INTRODUCTION

TO

THE SCIENCE OF HEAT,

DESIGNED FOR

THE USE OF SCHOOLS

AND

CANDIDATES FOR UNIVERSITY MATRICULATION EXAMINATIONS.

BY

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PREFACE.

THIS work is intended for those who possess a fair knowledge of arithmetic, and have an ordinary amount of intelligence. Many of the points discussed in it could have been explained in much less space with the use of symbols and formulæ; but it was not thought advisable to introduce such abstract considerations into a book written expressly for the use of schools. The examples are given, not for the purpose of teaching boys to substitute concrete for abstract numbers and to work out equations, but to induce them to think and to apply the principles which they have learnt in studying Pure Mathematics. Empirical rules are prejudicial to early progress in the Sciences; for a person may learn a formula, and work out correctly all questions that can be answered by means of it, without ever thoroughly understanding the reasoning which led to its adoption.

The *Metric* System of Weights and Measures has

been intentionally employed in the present volume. It will, doubtless, be objected that no examples have been given of the conversion of English into French measures; but it was thought that such examples, though they may teach the student how to multiply, can give him no *useful* knowledge of the Metric System. Moreover, the English measures are regarded by the author in much the same way as *caloric* is—as essentially bad, so that the less said of them the better.

The arithmetical accuracy to which the phenomena of Heat have been reduced renders this science peculiarly well adapted as a subject of education in superior schools. In this respect, Heat, Dynamics, and Chemistry stand to Pure Mathematics in much the same relation as that in which English, French, and German stand to the study of Latin and Greek. It is therefore to be regretted that, in the Matriculation Regulations of the University of London, Heat should be combined with Chemistry, while Light and Sound—subjects by no means so well suited for ordinary school education—have a far more prominent place allotted to them.

Scarcely any reference is made throughout this book to other works on Heat. The pupil, after perusing the following pages, is recommended to study the article on Heat in Watts's *Dictionary of Chemistry*;

also Dr. Tyndall's *Heat as a Mode of Motion*, several portions of which are masterpieces of lucid explanation. Dr. Balfour Stewart's *Elementary Treatise on Heat*, and Professor Tait's *Thermodynamics* will be most valuable aids to him when he has a connected view of the main facts of the science.

UNIVERSITY COLLEGE SCHOOL, LONDON,
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NATURE OF HEAT.

INTRODUCTION.

THE measures of length, capacity, and weight employed in the present work are those used on the Continent and by scientific men in all countries. This system is called the French, or the Metric, System.

Measures of Length.—One ten-millionth of the line drawn from the Equator to the North Pole through Paris is called a *metre;* its length is a little more than 1 yard 3 inches. Several other lengths are used, just as we have inches, feet, yards, miles, &c.; but the former, unlike the latter, are interconnected in a very simple way, as is seen by the following table:—

One milli-metre	=	·001 or 1-1000th	of a metre.
— centi-metre	=	·01 or 1-100th	,,
— deci-metre	=	·1 or 1-10th	,,
— metre			
— deca-metre	=	10	metres.
— hecto-metre	=	100	,,
— kilo-metre	=	1,000	,,

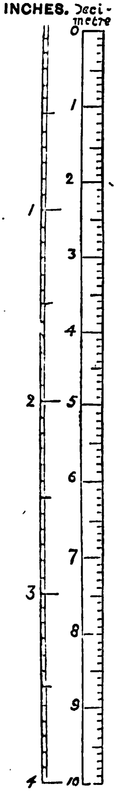

Fig. 1.

1 inch is a little more than 2·5 centimetres; and therefore a decimetre is about 4 inches, and a foot about 3 decimetres. A mile is somewhat more than 1·6 kilometre. Fig. 1 is very nearly an exact representation of a decimetre divided into centimetres and millimetres. There are 10 millimetres in a centimetre, 10 centimetres in a decimetre, 10 decametres in a hectometre, 100 decametres in a kilometre, and so on.

Questions on the Measures of Length.

1. How many centimetres are there in a hectometre?—*Ans.* 10,000.

2. How many decimetres are there in ·05 kilometre?—*Ans.* 500.

3. How many metres are there in 356·543 centimetres?—*Ans.* 3·56543.

4. What part of a metre is ·0115 decametre?—*Ans.* ·115 of a metre.

Measures of Capacity.—A cube, the edge of which is 1 decimetre (called therefore a cubic decimetre), is the unit of bulk or capacity, and is generally termed a *litre*. A litre, then, is a cubic decimetre; it *contains a little* more than 62 cubic inches, *i.e.* rather

more than a pint and three quarters. The other measures of capacity are related to the litre in the same way as the decimetre, the decametre, &c., are to the metre; thus a millilitre is ·001 of a litre; a decilitre is ·1 of a litre; a hectolitre is 100 litres, and so on.

Since 1 decimetre = 10 centimetres

1 cubic decimetre,

or a litre = 1,000 cubic centimetres.

And in the same way 1000 cubic decimetres, or litres make up 1 cubic metre or a kilolitre.* A cubic centimetre has the size of a small die; it is a millilitre.

QUESTIONS ON THE MEASURES OF CAPACITY.

1. How many decilitres are there in 1·35 decalitre?—*Ans.* 135.

2. How many centilitres are there in ·037 litre?—*Ans.* 3·7.

3. How many litres are there in 1·5 cubic metre?—*Ans.* 1,500.

4. How many cubic decimetres are there in ·054 cubic decametre?—*Ans.* 54,000.

5. What part of a cubic metre is a decalitre?—*Ans.* 1-100th.

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* The bulk of solids is given usually in cubic decimetres, cubic metres, &c.; that of liquids in litres, decalitres, &c.; either method is *employed in the case of gases.*

6. How many cubic metres are there in 1565976 cubic centimetres?—*Ans.* 1·565976.

Measures of Weight.—A cubic centimetre of water at a certain temperature (see further, p. 60) has a certain weight; this weight is called a gramme. A gramme, therefore, is the accurate weight of a cubic centimetre of pure water at a certain definite temperature, for at no other temperature than that fixed upon has a cubic centimetre this precise weight. At all other temperatures, this bulk of water weighs less than a gramme, as will be seen hereafter. In the same way as before, 1 milligramme is ·001 of a gramme; 1 decigramme is ·1 of a gramme, and so on. 1 ounce troy is rather more than 31 grammes; and 1 pound avoirdupois is not quite half a kilogramme. In the following examples, the water is supposed to be measured off in all cases at the particular temperature above referred to.

Questions on the Measures of Weight.

1. Find the weight of a litre of water.—*Ans.* 1 kilogramme.

2. Find the weight of 10 centilitres of water.—*Ans.* 1 hectogramme.

3. Find the weight of a cubic metre of water.—*Ans.* *1,000 kilogrammes.*

4. Find the weight of ·5 decalitre of water.—*Ans.* 5,000 grammes.

5. Find the bulk of 10·5 grammes of water.—*Ans.* ·0105 litre.

6. Find the bulk of 16 kilogrammes of water.—*Ans.* 16 cubic decimetres.

7. Find the bulk of 10·3 decagrammes of water.—*Ans.* 103 cubic centimetres.

A cubic centimetre of any other substance, as of mercury, at a certain fixed temperature, does not weigh 1 gramme; if it weighs more than 1 gramme, as is the case with mercury, it is said to be heavier than water, that is, bulk for bulk; if it weighs less than 1 gramme, as in the case of oil or wood, it is said to be lighter than water. But this subject will be entered into more fully when "Temperature" has been discussed. In the meantime, the student should provide himself with facsimiles of the measures of length, bulk, and weight; for example, with a metre rule, a litre cube, a cubic centimetre, and, if possible, with a gramme and a kilogramme. Very little real progress can be made in the metric system unless these standard measures are constantly before the eye.

For further particulars, see "Barff's Chemistry," pp. 266-9.

GENERAL NOTIONS.

If you were to remain for an hour in a brilliantly lighted room, and were then to remove into another room that was only very dimly lighted, this latter would appear to you to be quite dark or very nearly so; but the eye quickly adjusts itself, and you would perceive that it was not really dark, but only seemed to be so. If, on the other hand, you were to remain for some time in a very dark room, and were then to remove into the above-mentioned dimly lighted room, the latter would appear very well illuminated: but still it is no lighter than before when it appeared so dark; it has the same quantity of light in it. It has appeared both dark and light. The same phenomenon occurs with heat. A, B, and C are three basins; A is filled with very cold water, B with very hot water, and C with luke-warm water. If one hand is placed in A and the other in B, and they are allowed to remain so for some time, and are then both removed and plunged into C, the water in C will feel warm to the cold hand but cold to the hot hand. The same water has appeared both hot and cold. Why is this? Hot and cold are what we *call comparative terms;* water which is cold in summer *is, in the winter,* so hot that the frost-bitten hand can-

not bear it. A man working close to a furnace will go out into the sunshine to cool himself; but a man who works in a cold well will come into the same sunshine to warm himself. Things appear to us to be hot or cold according as we are cold or hot.

We say that a thing is hot because it has heat in it. Why is a thing cold? Is it because it has coldness in it? A consideration of the above experiment will at once show that this is not the proper answer. A room is dark—not because it has darkness in it—but because it has *not light* in it. Darkness means absence of light. In the same way a thing is said to be cold if there is less heat in it. Hence, in our study of heat, we shall never, or very rarely, speak of coldness, because it is only a negative word signifying *absence of heat*.

All substances which have been in one room for a long time must be, as we shall afterwards show, equally warm; but they do not feel equally warm to our hands. Spoons, steel knives, glass tumblers, marble substances, &c., appear to be very much colder than substances made of wood, cloth, flannel, &c. The reason of this is that silver, steel, and certain other substances have the power of carrying away the heat of our hands very rapidly, and this removal of heat produces the sensation of cold. Such substances as silver are called good *conductors* of heat, but wood is a bad conductor.

In Chemistry we learn that matter is indestructible; the corresponding truth in the subject before us is that *Force is indestructible:* you cannot permanently get rid of it. A kilogramme of boiling water A is mixed with a kilogramme of cold water B, and we obtain 2 kilogrammes of rather hot water C. There was a certain

quantity of heat in A and a certain quantity in B. Let us suppose that there were 9 measures of heat in A, and 1 measure of heat in B; there must be 10 measures of heat in C (9 measures + 1 measure), for none of the heat has been destroyed by the process of mixing—we cannot destroy heat. Thus we see that there is more heat in C than in A, and yet C is not so hot as A; and the reason of this is that, whereas the 9 measures of heat in A are spread over only 1 kilogramme of water, the 10 measures of heat in C are spread over 2 kilogrammes. The heat in C is spread over a greater weight, it is not so intense; the *intensity of the heat* is less. In order that 2 kilogrammes of water may feel as hot as 1 kilogramme of water, there must be double the quantity of heat in the 2 kilogrammes. We thus see that the intensity of the heat in a body depends not only upon the *quantity of heat* in that body, but also upon the *quantity of matter* in it. We use another and a more convenient term for intensity of heat; the *temperature* of a body means the intensity of the heat in that body. If a thing is intensely hot, its temperature is said to be high; a body is said to be at a very low temperature if the intensity of the heat in it is very slight.

CHAPTER I.

EXPANSION.

The great majority of substances expand when heated; that is, they increase in bulk or volume.

(1) *Gases.*—If a bladder is three-quarters filled with air and is then tied up and held before a fire, it bulges out in all directions and appears to become filled with air. This arises from the air occupying a larger bulk or volume at the higher temperature.

(2) *Liquids.*—The mercury of a thermometer rises in the small tube in warm weather because the mercury expands and occupies a greater space. If a kettle is completely filled with water and is placed on the fire, the water will expand and run down the outside of the kettle long before the water boils. If a narrow-necked bottle is filled with hot water and is then allowed to cool, the water will be observed to recede from the narrow neck, and when at the temperature of the surrounding air it will occupy only the broad portion of the bottle.

(3) *Solids.*—Solids expand so slightly when heated that a somewhat delicate apparatus is required to render

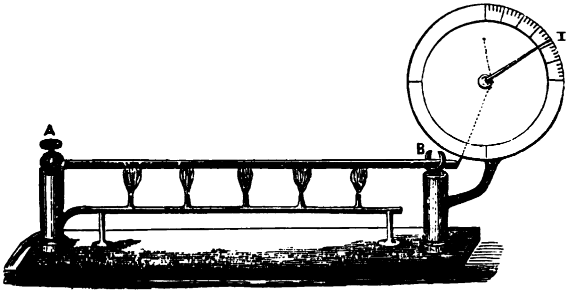

Fig. 2.

the expansion visible. A bar of iron A B (Fig. 2) is firmly fixed at A, and is provided at its other extremity with an elastic cord that passes tightly round a wheel supporting the index I. If the bar be heated, it elongates and allows the elastic cord to contract; but as the cord contracts, the wheel revolves and the index with it. The bar on cooling, contracts and pulls the elastic cord with it, and thus the index I returns to its former position. This shows that substances not only expand when heated, but contract again to their original bulk on cooling.

How is it that substances do not expand without being heated? and how is it that they do expand when heated? There are certain forces at work in every substance, such as the force of cohesion. In a bar of iron, all the particles of iron tend to cohere or stick together, and it requires great force to break the bar *into two pieces.* Now, when the bar of iron expands,

the particles of iron separate to a very small extent, and the force of cohesion is partially overcome. Heat, therefore, will overcome the force of cohesion, and cause the bar to expand; but the bar will not expand spontaneously because of this force of cohesion. But cohesion is not the only force at work in the bar, as we shall presently see. In the same way the different particles of a liquid cohere, and consequently the above remarks apply to liquids as well as to solids. But, when we come to gases, we find that, *for all practical purposes*, the particles of a gas do not cohere *; the atmosphere—a huge body of gas—does not, like the sea, remain at or near the surface of the earth, but extends to a distance of 70 or 80 kilometres above the sea's level. What force, then, prevented the air in the bladder from expanding spontaneously and filling it without the agency of heat? The weight or pressure of the atmosphere. If this weight be removed from the bladder, as by placing the bladder in the bell-jar of an air-pump, and then exhausting the jar, the bladder will bulge out just as if it were heated, and, if not strong enough, will burst. Does not the pressure of the atmosphere prevent solids and liquids from expanding? Yes; but the effect of atmospheric pressure on the expansion of solids and liquids is very slight indeed when compared with that of the other forces, to one of which—cohesion—we have above referred.

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* See further, p. 64, and Chapter VIII.

CHAPTER II.

EXPANSION OF SOLIDS.

Solids expand less than either liquids or gases, and so we will study their expansion first. Suppose we had a cubical block of some solid—say a large die made of lead—and suppose the edge of the die measured exactly 1 decimetre. This block would then be 1 decimetre long, 1 decimetre broad, and 1 decimetre deep or thick. The length, breadth, and thickness are called the *three dimensions* of the block. The face of it, *i.e.* any of the surfaces upon which it can stand, forms a square, and each of the four sides of the square is a decimetre; the face or superficies of the cube is 1 square decimetre. The whole bulk or volume of the cube, or its cubical contents, is 1 cubic decimetre.

Now, if such a cube as this were heated, it would expand equally in all directions. If the length were to expand by 1-1000th of a decimetre (·001 decimetre), *i.e.* if the length were to become 1·001 decimetre, the breadth would likewise become 1·001 decimetre, so also the depth. We should have a larger cube than before; the edge of this larger cube would be 1·001 decimetre; its face or superficies would be a square, each of whose sides would be 1·001 decimetre. Now, the increase in *the edge is called linear expansion*; the increase in the

face, *superficial expansion;* and the increase in the whole bulk, *cubical expansion.*

When we consider linear expansion, we have expansion in only one direction—length, breadth, or depth; but in superficial expansion, we have expansion in two directions—*e.g.* length and breadth; and in cubical expansion, we have expansion in three directions—length, breadth, and depth. It is found by experiment that the superficial expansion of one side of a cube is twice as great as the linear expansion of one of the edges of the cube, and that the cubical expansion is three times as great as the linear expansion. For example, a cube of iron, the length of whose edge in freezing water is 1 decimetre, expands when put into boiling water, and the edge becomes 1·00118 decimetre long. Hence the linear expansion is ·00118 decimetre; its superficial expansion is twice ·00118, or ·00236 square decimetre, so that the area of its side becomes 1·00236 square decimetre; and its cubical expansion is three times ·00118, or ·00354 cubic decimetre, so that the bulk of the cube becomes 1·00354 cubic decimetre.

There is much difference between the temperatures of freezing and of boiling water, and yet the iron expands very slightly; and iron is one of the most expansible of solids. As a rule, metals expand more than other solids.

To determine the linear expansion of a solid, one end of a rod of that solid is immoveably fixed to a support, and the whole is immersed in a mixture of ice and water. The length of the rod is then observed with the utmost care. After this, the ice is removed; and the rod is raised to the temperature of boiling water,

by surrounding it with the steam of boiling water, and when the rod is at that temperature the length is again accurately noted. The increase in the length of the rod is, of course, the amount of expansion undergone by a rod of the length chosen, when heated from the freezing to the boiling temperature of water. Suppose that a rod of copper, 2 decimetres long in freezing water, expanded when immersed in steam, and measured 2·00344 decimetres. The amount of expansion undergone by 2 decimetres of copper is ·00344, and therefore the amount undergone by 1 decimetre is ·00172, *i.e.* half of ·00344. Hence the amount of expansion on 1 metre (10 decimetres) of copper is ten times ·00172 decimetre, or ·00172 metre. The following table gives the amount of expansion undergone by rods of the various substances named (each rod supposed to be 1 decimetre long) when heated from the freezing to the boiling temperature of water :—

Glass tube	·00086	of a decimetre
Platinum	·00088	,,
Steel, untempered	·00108	,,
Iron	·00118	,,
Steel, tempered, yellow	·00137	,,
Gold	·00138	,,
Copper	·00172	,,
Silver	·00199	,,
Tin	·00273	,,
Lead	·00301	,,

Solids have what is called a SPECIFIC EXPANSIBILITY, *i.e.* each solid has its own peculiar rate of expansion—some expanding more than others, and metals, as a *rule, expanding* more than other solids, as already

mentioned. But glass tube and platinum expand to very nearly the same extent, and therefore, when hot, they both contract to very nearly the same extent on cooling. Thus, if platinum is made red-hot, and is then thrust into fused glass, they do not separate on cooling; but if copper wire had been used instead of platinum wire, the copper would have contracted much more than the glass, and would have receded from it, leaving a hole indicating its former position. A eudiometer is made "by strongly heating the end of the tube in the blow-pipe flame, and then just touching it at the point where the wire is to be introduced with a hot platinum wire; to this the glass strongly adheres, and by this means is drawn out to a fine thread, which, on being cut off close to the eudiometer, is found to be hollow; through this hole a platinum wire is introduced, and the glass carefully fused all around it."—

W. J. Russell.

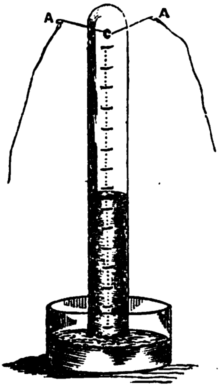

Fig. 3.

Fig. 3 represents a eudiometer provided with platinum wires.

Many circumstances have a great influence upon the amount of expansion. Steel, for example, expands more when tempered than when not tempered; and iron has a different rate of expansion, according as it contains more or less carbon (cast iron, steel, and wrought iron). But the most *important circumstance* to note here is the influence of *temperature. If a* glass rod, which is 1 metre long in

boiling water, is heated till it is as much hotter than boiling water as boiling water is hotter than ice, its linear expansion is ·00092 metre; and if 1 metre of glass tube measured at this higher temperature is heated till it becomes as much hotter as boiling water is hotter than ice, its linear expansion is ·00101 metre. Now, if we compare these numbers with that given in the table above, ·00086, we see that the linear expansion increases with the temperature. Other solids follow the same general rule; the hotter they are the more they expand for the same increase of temperature. It is clear that the superficial and the cubical expansion of solids must likewise be more rapid at high than at low temperatures.

Examples on the Expansion of Solids.

1. A bar of iron is 5 decimetres long when immersed in freezing water; what is its length in boiling water?

A bar 1 decimetre long becomes 1·00118 decimetre when similarly treated;

∴ a bar 5 decimetres „ $5 \times 1{\cdot}00118$ „

or 5·0059 „

Ans. 5·0059 decimetres.

2. A bar of copper is 4 decametres long when immersed in boiling water; what is its length in freezing water?

A bar 1·00172 decametre long becomes 1 decametre when similarly treated;

∴ „ 1 „ „ $\dfrac{1}{1{\cdot}00172}$ „

∴ „ 4 „ „ $\dfrac{4}{1{\cdot}00172}$ „

or 39·93 metres.

—*Ans.* 39·93 metres.

3. 13 centimetres of glass tube are measured off in ice, and are then heated till they are as much hotter than boiling water as the latter is hotter than ice; what is then the length of the tube?

We will suppose the glass to be heated first of all to the temperature of boiling water, and secondly to the higher temperature.

Since 1	centimetre	of glass tube	in ice	becomes	1·00086	centimetre in boiling water,
and 1	,,	,,	in boiling water	,,	1·00092	,, at the higher temp.
∴ 1·00086	,,	,,	,,		$1{\cdot}00092 \times 1{\cdot}00086$	,,
					$= 1{\cdot}00178$	,,
∴ 1	,,	,,	in ice	becomes	1·00178	,,
∴ 13	,,	,,	,,	,,	$13 \times 1{\cdot}00178$	,,
					$= 13{\cdot}02314$	,,

Ans. ·1302314 metre.

4. Two rods, one of copper, the other of iron, both measure 3·5 decimetres in freezing water; when both are transferred to boiling water, which rod is the longer, and by how much?—*Ans.* The copper rod by ·189 millimetre.

5. What length of untempered steel expands by 1·8 millimetre when removed from freezing to boiling water?—*Ans.* 1·6667 metre.

6. 1·2 decimetre of glass tube is measured off at the higher temperature mentioned in Example 3; what is its length in boiling water, and also in freezing water?—*Ans.* ·1198898 metre; ·1197868 metre.

When a solid is heated it expands, because the heat overcomes those forces which tend to keep the particles of the solid close together. Now we can overcome these forces by mechanical force, though with great difficulty;

and thus heat answers the same purpose as the process of pulling. In the same way, if a solid is heated and is then left to cool, it contracts just as if it were subjected to great pressure: and the force exerted by hot iron in cooling is made use of in the construction of cart-wheels. The tire is an iron hoop which is rather too small to pass over the wooden framework of the wheel; but when heated it expands and can then be passed over the framework. As it cools, it contracts and clasps the wheel with enormous force. The expansion of iron has to be taken into consideration in the construction of iron bridges, and in the laying down of railroads. In the latter case, for instance, if the separate bars of iron were put along the road so as to be close together when cold, they would expand in hot weather and thrust one another upwards, and thus disarrange the railroad. Hence there is always a small interval of a few millimetres left between each two consecutive bars.

EXAMPLE. 30,000 bars of iron, each 1·5 metre long in ice, are to be laid down during a frost lengthwise between two points A and B, and the bars are to be at equal distances from one another; what must be the distance between any two consecutive bars, so that, when all of them are heated to the temperature of boiling water, they shall just touch each other, it being supposed that one extremity of the first bar is fixed firmly at A, and the opposite extremity of the last bar firmly at B? Also find the distance between A and B, *i.e.* the length of the 30,000 bars at the temperature of boiling water.—*Ans.* 1·77 millimetre; 45·0531 kilometres.

A Compound Bar (Fig. 4) is a metallic bar consist-

ing of platinum and copper, or of platinum and iron, firmly soldered together, end to end. When such a bar is heated, both the metals expand, but the platinum expands least. The two metals cannot separate at their ends and expand like separate bars of each metal: they must remain together, and yet one side of the bar must expand more than the other side. Hence, when heated, the compound bar bends, and the concave or smaller surface is the platinum one. For a similar reason, when cooled, the bar becomes straight again.

Fig. 4.

A pendulum is a metallic rod supporting a weight, or bob, and it is made to oscillate by a certain contrivance. The rate of its oscillation depends, to a great extent, upon the distance of what is called the centre of oscillation from its point of suspension. Now, the centre of oscillation is situated in the bob; but the distance of this centre from the point of suspension is greater in hot than in cold weather, because the metallic rod is longer. Hence a clock loses time in summer and gains time in winter, unless suitable precautions are taken. To compensate for this effect of temperature, pendulums have been contrived which are not practically lengthened when the temperature rises.

The *Gridiron Pendulum* has the shape given in Fig. 5. It is constructed of two different metals, as steel (A B, C D), and brass (E F, G H). The brass expands upwards more than the steel does downwards, so that, by using a proper length of brass, the distance

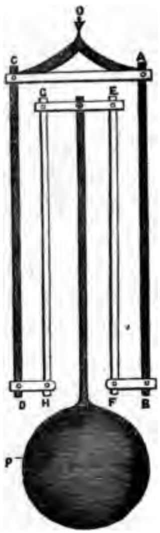

Fig. 5.

between O and P can be made constant at all temperatures likely to occur in practice. When carefully made, this pendulum is much more accurate than the following:—The rod of the pendulum (Fig. 6) is enlarged at its lower extremity, and a glass vessel almost full of mercury is placed in the enlarged portion. When a rise of temperature occurs, the rod lengthens downwards, but the mercury expands upwards in the vessel. The principle of this is exactly the same as that of the Gridiron Pendulum, but the mercury is much more sensitive to change of temperature than the metallic rod, and consequently will often rise slightly in the vessel when the rod itself is not affected.

The *Balance-wheel* of a watch expands in warm weather, and consequently turns slower. The following contrivance is therefore employed

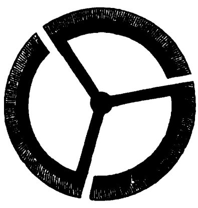

Fig. 7.

in the construction of chronometers. The circumference has the form given to it in Fig. 7, but consists of two metals closely fitted together, the outer one expanding the most. When the temperature rises, the diameter of the wheel increases, but the parts of the circumference bend inwards, each part being a compound bar. If the temperature falls, the diameter diminishes and the circumference bends outwards. By this means the expansion of the diameter is compensated for, and the rate of turning remains constant.

If a bar of iron measures 1 metre when immersed in freezing water, it will measure 1·00118 metre in boiling water. Knowing this fact, we might have a bar whose length was exactly 1 metre at the temperature of freezing water; and, if we wished to determine the temperature of any other sample of water, or of an oil, we should only have to immerse the bar of iron in it, and read off its length accurately; if this length was 1·00118 metre, we should know that the water boiled, or that the oil was at the same temperature as boiling water. Now the increase in the length is so small that it is difficult, and in most cases impossible, to ascertain it with any degree of accuracy, because we should generally be obliged to use a bar shorter than 1 metre, and therefore the absolute amount of expansion would be less. But, by the following contrivance, any change of temperature, though very slight, is readily observable.—*Breguet's* Thermometer.* A *thermometer* is an instrument employed for the measurement of temperature. Breguet's ther-

* *Abraham L. Breguet*, a Swiss watchmaker (1747—1823).

Fig. 8.

mometer (Fig. 8) consists of a spiral coil, which is made up of two metals, platinum and silver, firmly soldered together by a thin layer of gold. The silver is on the outside of the coil, the platinum on the inside; so that any rise of temperature is indicated by the spiral coiling up. The spiral carries an index which moves over a graduated scale. If the temperature falls, the spiral uncoils and the index moves back again.

We have adverted to the great objection against using the increase in the length of a metallic bar as a means of determining the temperature to which the bar is exposed; but, if we wish to determine excessively high temperatures, we must in many cases overlook this objection, as it is one of the only methods at our disposal: instruments used for these high temperatures are called *Pyrometers* (measurers of fire). *Wedgwood's* * pyrometer was an instrument for measuring high temperatures by the contraction of a pellet of baked clay when heated; but this has long gone out of use, since a permanent low temperature will produce the same effect upon the clay as a high temperature of short continuance.

Daniell's † pyrometer (Fig. 9) is more accurate, but

* Josiah Wedgwood (1730-95).

† John Frederick Daniell (1790—1845).

the indications must still be regarded only as approximations. A tube of well-baked plumbago (A) contains a bar of iron (B), and the tube is closed by a tightly-fitting porcelain plug (C). When this is put into a furnace, the plumbago, the iron, and the porcelain all expand, but the iron expands the most, and forces up the porcelain plug. On removal, the instrument cools; but the plug remains where it is, since it fits tightly in the tube; a scale is then fixed on to the apparatus, and the index indicates the temperature.

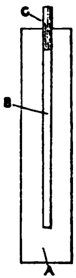

Fig. 9.

The *Cubical Expansion* of a solid can be found from the linear expansion by multiplying the latter by 3. The following table gives the cubical expansions of several solids when heated from the temperature of freezing to that of boiling water: the second column, headed "Calculated," is obtained by multiplying the linear expansions by 3; the third column contains the cubical expansions, found by direct experiment. The third column agrees very generally with the second; where discrepancies occur, the linear and the cubical expansion were determined for *different specimens* of the same solid, and these differed in the amount of their impurities, &c.

	Calculated.	Found.
Glass tube	·00258	·00258
Platinum	·00264	·00265
Iron	·00354	·00355
Copper	·00516	·00515
Tin	·00819	·00689
Lead	·00903	·00889

The third column of numbers can be found by either of the following methods :—

(1.) Since a cube increases in bulk as its temperature rises, it follows that its relative weight diminishes as the temperature rises.* Hence, by finding its relative weight at different temperatures, we can deduce the amount of expansion undergone ; if the relative weight becomes halved, we know the volume has been doubled. Suppose a cubic centimetre of a metal weighs 12 grammes at the freezing temperature of water ; its relative weight at that temperature, as compared with water, is then 12 ; but suppose its relative weight at the boiling temperature of water is 11·91—what amount of expansion has it undergone ? Its bulk at the boiling temperature is

1 cubic centimetre + the volume by which it has expanded.

The 1 cubic centimetre weighs 11·91 grammes, and the whole bulk together weighs 12 grammes ; therefore the volume by which it has expanded must weigh 12 — 11·91, or ·09 gramme.

Now 11·91 grammes occupy 1 cubic centimetre

$\therefore$ 1 gramme occupies $\frac{1}{11{\cdot}91}$ cubic centimetre

$\therefore$ ·09 gramme occupies $\frac{\cdot 09}{11{\cdot}91}$ cubic centimetre

= ·00756 cubic centimetre nearly.

Hence the bulk at the boiling temperature is 1·00756 cubic centimetre, and the cubical expansion is ·00756.

Example 1. The relative weight of a solid at the temperature of freezing water is 18, but at the temperature

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* See p. 44.

of boiling water it is 17·982; what is the bulk of 1 cubic decimetre of the solid measured off at the freezing temperature when it is immersed in boiling water? —*Ans.* 1001·001 cubic centimetres.

2. Three cubic metres of a solid measured in freezing water become 3·01 cubic metres when immersed in boiling water. The relative weight of the solid at the former temperature is 7·8; find the relative weight at the latter.—*Ans.* 7·774.

(2.) The second method to be described is that employed by Dulong* and Petit. The metal to be examined was put into a glass tube, and the unoccupied space in the tube was measured at the freezing and at the boiling temperature of water by filling the space with mercury, corrections being made for the expansion of the tube itself and of the mercury. Supposing these corrections to have been made, the difference between the two spaces is evidently equal to the cubical expansion of the metal.

Finally, some solids when heated do not expand, but contract. Vulcanised caoutchouc is one of these; another is a remarkable alloy of 1 part of lead, 1 part of tin, and 2 parts of bismuth—three metals. When the temperature of this alloy is gradually raised, the solid first of all expands and then contracts; and on being still further heated it expands again, and finally fuses. These facts decisively prove that cohesion is not the only force at work in solid bodies; there are other forces exerted by the particles upon one another, but almost all that we know of these forces is that there are such.

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* *Peter Lewis* Dulong, 1785—1838.

CHAPTER III.

CONDUCTION OF HEAT.

The term "conductor of heat" was explained when the sensation produced by touching a good conductor was described. A person's hand is generally hotter than the objects which he touches, and consequently good conductors generally feel colder than bad conductors. But, if both the good and the bad conductors of heat are hotter than the hand, then the good conductors feel hotter than the bad ones, though they are not in reality so. A good conductor feels hotter than a bad one, because no sooner is the touched part cooled by contact with the hand than heat flows to that part from other portions of the mass. This is not the case with bad conductors; the handle of a kettle or of a teapot should be made of some material that conducts heat badly.

Of all solids metals are the best conductors, and the superior conductivity of iron is made use of in Sir Humphry Davy's* Safety Lamp; the heat produced by the combustion within the lamp is so completely conducted away by the wire gauze, that the explosive gases outside the lamp cannot become ignited.† Another

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* Sir Humphry Davy, 1778—1829.

† *See* Barff's Chemistry, p. 86.

striking illustration of the conductivity of heat possessed by metals is the following :—A brass cylinder is covered tightly with tissue paper and is then held over a flame; the paper is not scorched for some little time, owing to the withdrawal of the heat by the brass; but if a wooden cylinder is used instead of a brass one, the paper becomes scorched almost instantly. If some oil of turpentine is dropped upon a flagstone and ignited, the flame will soon be extinguished, the rest of the oil remaining unburnt; in this case the heat produced by the combustion is so rapidly removed that the combustion cannot continue; but, if the oil is poured upon a block of wood instead, the heat of combustion is not withdrawn, but accumulates, and the whole of the oil burns away.

If two similar bars, one of copper and the other of iron, are heated at one end, the opposite end of the copper bar will become hot long before the corresponding end of the iron bar. It is very natural to conclude from this that copper is a better conductor of heat than iron is; but it will be shown in a future chapter that this is by no means a logical conclusion. Copper *is* a better conductor of heat than iron, and this fact is ascertained in the following way :—A long bar of the metal to be examined is heated at one end by some constant source of heat, the temperature of which is constant, as molten lead. The heat flows from the molten lead along the bar, which gets hotter and hotter; but in course of time it is found that the bar is as hot as it can get; when the bar is in this state, whatever heat flows along it from the lead is removed *by the surrounding* air. Now the bar is not equally

hot throughout its whole length; at a certain distance from the lead it has the same temperature as the surrounding air, and as we proceed along the bar to the lead we find that it becomes hotter; but if we proceed along the bar away from the lead we find that the bar has the same temperature as the air. Now that point in the bar which is nearest to the lead, and has the same temperature as the air, is much more distant from the lead in a good than in a bad conductor. In this way it is found that, of all solids, metals are the best conductors; and the order of conductivity for a few important metals, beginning with the best conductors, is—silver, copper, gold, brass, tin, iron, steel, lead, platinum, and bismuth. Next after metals come the dense varieties of carbon—diamond, graphite, gas carbon, &c. Wood is an inferior conductor; it conducts heat better in the direction of its fibres than across its fibres, but this difference is less marked in the dense kinds of wood than in the soft varieties. Articles of clothing, flannel, feathers, eiderdown, &c., are very bad conductors of heat; hence their use—they do not carry away the heat of the body. For the same reason flannel is much used in the preservation of ice, for the heat of the atmosphere cannot penetrate the flannel in which the ice is enclosed. Certain crystals have a remarkable behaviour towards heat. In order to ascertain how crystals conduct heat, a slice of the crystal is covered with wax, and a wire, which is kept at a fixed temperature by means of a voltaic battery, is passed through a hole in the centre of the slice. The conduction of the heat is rendered visible by the melting of the wax. Now, if the crystal conducted heat

equally in all directions, the melted wax would form a circle round the wire; but this is not the case: the conductivity of the crystal is greater in one direction than in the other, and the figure described by the melted wax around the wire is like a somewhat elongated circle—an ellipse.

CHAPTER IV.

EXPANSION OF LIQUIDS.

We pass on now to liquids; which, when heated, increase in bulk far more than solids do. As with solids, so also with liquids, each has its own peculiar rate of expansion—*a specific expansibility;* thus alcohol is more expansible than water. To determine the expansibility of a liquid, however, appears from the following considerations, to be a very difficult problem. Liquids, in order to be examined, must be contained in a vessel of some description, *e.g.* a glass vessel.

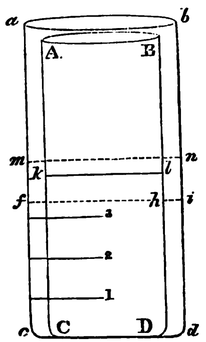

Fig. 10.

Now the liquid cannot be heated without the vessel being heated also, and therefore the vessel as well as the liquid expands. To make this point clearer, let A B D C (Fig. 10) represent the glass vessel filled with liquid up to the level *k l*. The vessel is graduated into cubic centimetres, as at 1, 2, and 3. There are 4 cubic centimetres of liquid in the vessel when the vessel is at the freez-

ing temperature of water. Now, if we raise the liquid to the boiling temperature of water, we must do the same with the vessel *at the same time.* Let us suppose it possible to heat first the vessel and then the liquid. If the vessel is heated it expands, say to *a b d c*, and the level of the liquid consequently falls from *k l* to *f i*, so that the two spaces *f* C and *i* D are together equal to the space *k h*. The liquid appears to have a less bulk than before; it appears to occupy a little more than $3\frac{1}{3}$ cubic centimetres. If the liquid is now heated, it expands, and the level rises from *f i* to *m n*, and appears to occupy about $4\frac{1}{3}$ cubic centimetres. Now, as the vessel and the liquid cannot be heated separately, all the expansion undergone by the liquid, that is apparent, is from the level *k l* to the level *m n*—from 4 cubic centimetres to $4\frac{1}{3}$ cubic centimetres; the apparent expansion of the liquid is therefore $\frac{1}{3}$ cubic centimetre. But the real expansion of the liquid is much more than this; it is $\frac{1}{3}$ cubic centimetre together with the expansion due to the glass vessel; and, as we shall afterwards show, there is no method by which we can ascertain the expansion due to the glass vessel without previously knowing the real expansion of the liquid. If by any means we can find the real expansion of the liquid, we have only to deduct from that the apparent expansion of the liquid in any vessel, and the remainder will be the expansion of the vessel used. That the vessel containing the liquid does indeed expand, and vitiate the result of our observations, is proved by the following experiment:—A glass flask, completely filled with a coloured liquid, is provided with a tightly-fitting cork, through which passes a

tube that also contains some of the coloured liquid ; the upper level of the liquid in the tube is marked by a small indiarubber ring. Now, if the flask is suddenly plunged into boiling water, the flask is heated and expands before the liquid within it is much affected; and consequently the level of the liquid in the tube falls considerably. But, if the flask is retained in the boiling water, the level of the liquid gradually rises, and at last remains stationary at some distance above its former level as marked by the indiarubber ring. This final level is now marked by another ring, the flask is removed from the boiling water, and is cooled* down to its former temperature, the level of the liquid being then at the indiarubber ring that was first put on. If the flask is now put into cold water, and the latter is gradually heated up to the boiling point, the flask and the liquid in it are heated and expand together, so that the level of the liquid does not fall below the indiarubber ring at all, but gradually rises until, when at the boiling temperature, it stands level with the indiarubber ring last put on. The distance between the two indiarubber rings marks the apparent expansion of the liquid. The absolute expansion of the liquid is the apparent expansion of it *together with another quantity as yet unknown.* (See Fig. 21.)

The *Mercurial Thermometer*, the one in common use, is the most important instrument that we have to describe in speaking of the expansibility of liquids. A

* If it be cooled suddenly by being immersed in cold water, an effect will be produced which is the exact opposite of that produced by immersing the instrument when cold in boiling water; *the glass will contract* first and force the column of liquid still *higher in the tube*

glass capillary tube, *i.e.* one of very small bore, is selected, about half as long again as the thermometer is intended to be. The bore is sometimes circular; but sometimes flat, so that a liquid contained in the tube can be seen only when the tube is so held that the broad flat bore faces you. But, of whatever shape the bore is, it will shortly be seen that it must be regular throughout, that is, not broad at one part and drawn out very fine at another. To ascertain whether the bore is regular or not, about 1 centimetre length of the tube is filled with mercury, and this mercury is then moved up and down the tube, the length of the column being accurately measured by means of a microscope in every new position. If the bore is regular, the column of mercury will measure 1 centimetre in all positions; but, if the bore becomes narrower, it will measure more than 1 centimetre; if broader, less than 1 centimetre; and allowance has to be made for any such inaccuracy in the bore. This process is called *calibration* of the tube. The end, A, of the tube is now melted in the blow-pipe flame, and a bulb of the requisite shape is blown. For chemical and physical research, the form of bulb most generally useful is represented in Fig. 11; but a globular bulb is

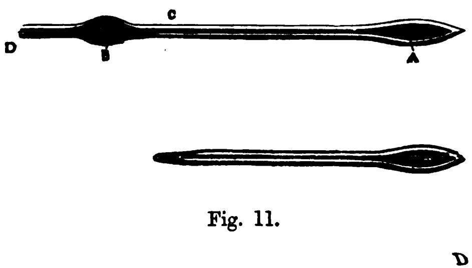

Fig. 11.

the common one for thermometers made for domestic purposes. The thermometer is to be of a certain length, say A C. Beyond C blow another bulb, larger than the first. The mercury is now introduced into this instrument in the following way:—The bulb A is heated in a lamp, by which means a great deal of the air is expelled from the apparatus, and the open end, D, of the tube is immediately placed under pure dry mercury; as the air cools inside the tube, it contracts, and the mercury is forced up by the pressure of the external air into B, which becomes about half full. This is one reason why the bulb B was blown; for if there had been no such bulb, the mercury would have at once risen into A, while the latter was still very hot, and this might cause the instrument to crack. As soon as A is cold, the tube is removed from the vessel of mercury, and is held vertically, D pointing upwards. A is again heated and the air in it expands, and partially escapes through the mercury in B, but cannot return; so that when A is allowed to cool the mercury in B is forced down into A; but still a little air remains in A; by successively warming and cooling it, the whole of it can be expelled, and A, the capillary tube, and a part of B, are thus filled with the liquid. The mercury is now boiled by holding A over a flame; this is to expel the air which is contained not only in the tube but also in the mercury, just as we find air in water; also any moisture that may be in the apparatus is expelled at the same time. When the operator is of opinion that these two impurities have been expelled, he applies a flame to D, so as to heat it, and while the mercury is still boiling, and the mercury vapour is still passing out at D, a piece of wax is pressed against D,

and the tube is immediately withdrawn from the flame. The mercury stops boiling and the melted wax solidifies in the bore, thus preventing air from entering. If there is more mercury in the tube than is required, a part of it is emptied into B by heating the mercury, and holding the tube in a somewhat inclined position, so that the mercury falls into B, but cannot return with the rest of the mercury when the latter, on cooling, recedes. The bulb B is then drawn off by fusing the tube at C in the blow-pipe.

The instrument is now in a condition to indicate temperatures. When the mercury is at the temperature of the air, it stands at a certain height in the capillary tube; if it is made hotter, it rises in the tube; if colder, it falls in the tube; but so long as the temperature remains constant the height of the mercury is likewise constant. One thing, however, has to be carefully remembered and fully appreciated, namely, that the bulb, which has been strongly heated, even fused, does not contract to its full extent until some few weeks have elapsed; the atmosphere presses on the bulb with a force of about 103·3 kilogrammes on the square decimetre, and consequently the capacity of the bulb diminishes slightly after the instrument is made. This diminution in the capacity of the bulb causes the level of the mercury to rise a little in the stem during the first few weeks; but, after this, the bulb has been compressed by the atmosphere about as much as it can be.

As yet, however, the instrument is of no great practical use as an indicator of temperatures, for we have no means of *recording its* indications, or even of forming *any idea of their* relative values. We must have a

point to start from, and the point that may suggest itself to the student is the freezing temperature of water, or the melting point of ice, for, under ordinary conditions, these two temperatures are one and the same. The starting point, then, is found in the following way. After the thermometer has been kept for a few weeks for the above-mentioned reasons, it is immersed, upright, in melting snow or pounded ice, the water that melts being allowed to drain off. The mercurial column falls in the tube, and care must be taken that the whole of the column is immersed in the ice, otherwise the portion not immersed would not be precisely at the freezing temperature of water, but somewhat above that temperature. As soon as the mercury has ceased to fall in the tube, which is about half an hour after immersion, its height in the tube is marked on the glass by means of a diamond. If the tube were not placed upright, but horizontally, in the ice, the mercury would not fall quite so low in the tube, because it would not be subjected to its own pressure in the direction of the tube.

We have now the starting point; but a little thought will enable the student to see that even this, by itself, is not sufficient. With one point, our only means of recording the temperatures indicated would be to say that the mercury rose to, say, 1 centimetre above the freezing point of water; but, if the bore was very narrow indeed, this temperature would be very slightly above the starting point; if very broad, it might indicate a very high temperature. The statement—1 centimetre above the freezing point of water—would be *absolutely without* any meaning, as it might stand for *any temperature* at which mercury can exist in the

liquid state. If, however, we have another point on the capillary tube, we shall be able to record the indications of the thermometer in a very precise manner, and the statements with regard to one thermometer will be true of all others that are made with mercury and the same kind of glass. This second point is the boiling temperature of water under ordinary conditions, or, which is the same thing, the condensing temperature of steam. The thermometer is held upright in the steam of pure water that is boiling in a metallic vessel (Fig. 11 A) under an atmospheric pressure of ·76 metre of mercury; the neck of the vessel, in which the water is boiled, is provided with a cylindrical cover having a wide opening at A; the thermometer passes through a cork which fits tightly into the cover. The course of the steam is indicated by the arrows, and it is clear that the cover is for the purpose of preventing the comparatively cold air from affecting the mercurial column. When the mercury has ceased to rise, the tube is drawn through the cork until its upper level is visible; a mark is instantly made on the tube at this point, and the thermometer is removed from the apparatus.

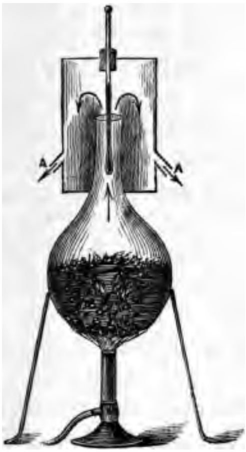

Fig. 11 A.

Now, whenever this thermometer is immersed in freezing water, the mercury falls to the first point marked on the tube; and, whenever it is immersed in the steam of boiling water, the mercury rises to the point last made. Pure water always freezes at the same temperature, and it always boils at the same temperature, if other conditions, such as the pressure of the air, are the same. This is one reason why these two points are fixed upon as starting points; another reason is that water is very easily obtained in a perfectly pure state. The interval between these two points has now to be divided into a certain number of equal parts, called degrees. The melting point of ice (or the freezing point of water, often called for the sake of brevity "freezing point") is spoken of as zero, or nought degree, written thus, 0°; and, as we divide the interval into 100 equal parts, the condensing point of steam (or the boiling point of water, often called for the sake of brevity "boiling point") is 100°, *i.e.* 100 degrees. As there are 100 degrees, or grades, between the two fixed points, the thermometer when thus graduated is called the *Centigrade* thermometer. Any temperature below 0°, say 5 degrees below 0°, is marked thus, —5°. The ordinary temperature of the air is from 15° to 16°. This mode of graduating the thermometric scale was originated by Celsius, of Upsal, about 1740; it is employed in France, and in the great majority of scientific works. The choice of numbers for the two starting points is evidently a matter of convenience, not of necessity, and we might call them by other numbers. Such, indeed, was done in *the early part* of the eighteenth century by Daniel G. *Fahrenheit (d. 1740)*, who called the freezing point of

water 32°, and the boiling point 212°, thus dividing the interval into 180 equal parts (212—32); and again, about the same time by Réaumur (1683—1757), whose numbers for these points were 0° and 80° respectively. These scales, in order to distinguish them, are named after their originators, and each degree is generally followed by the initial letter of the originator's name, thus:—

Freezing point of Water.	Boiling point of Water.		
0°C.	100°C.	on the Centigrade	scale
0°R.	80°R.	,, Réaumur	,,
32°F.	212°F.	,, Fahrenheit	,,

The interval between the two starting points is evidently quite independent of its subdivision; it is the same on the three scales, but it is subdivided differently on each. On the Centigrade scale (Fig. 12) it is divided into 100 equal parts; on the Réaumur scale into 80 equal parts; and on the Fahrenheit scale into 180 equal parts. In short, 100 Centigrade parts, or divisions, are equal to 80 Réaumur divisions, or to 180 Fahrenheit divisions; and this connection, therefore, subsists between the three scales. It is often necessary to remember this simple connection, and to make use of it. It is of the greatest importance to know the precise meaning of any

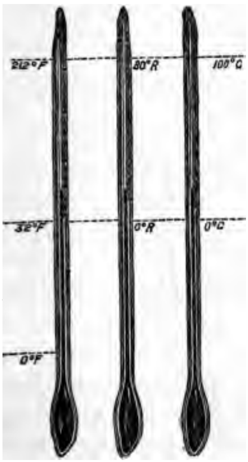

Fig. 12.

number of degrees on any scale; thus, 10°C. means 10 Centigrade divisions above the freezing point of water, —10°C. means 10 Centigrade divisions below it; 52°F. means 20 Fahrenheit divisions above it, 20°F. means 12 Fahrenheit divisions below it, and so on.

The ordinary temperature of the air is 15°C.; what is this degree as expressed upon the Réaumur scale? Now, 15°C. means a point above the freezing point of water and distant from it by 15 Centigrade divisions;

but	100 Centigrade	divisions	$=80$	Réaumur	divisions
$\therefore$	1 ,,	,,	$=\cdot 8$		,,
$\therefore$	15 ,,	,,	$=\cdot 8 \times 15$		,,
			$=12$		,,

Therefore 15°C. is represented by a degree on the Réaumur scale that is 12 Réaumur divisions above the freezing point of water, or by 12°R.

To find the equivalent of 12°R. on the Fahrenheit scale, we proceed as follows:—

$\because$	80 Réaumur	divisions	$= 180$ Fahrenheit	divisions
$\therefore$	12 ,,	,,	$= 2{\cdot}25 \times 12$	,,

or 27 Fahrenheit divisions. Hence 12°R. is equivalent to 27 Fahrenheit divisions above the freezing point of water (32°F.): the answer is, therefore, 32 + 27, or 59°F.

To find —5°C. on the Fahrenheit scale, we must find what Fahrenheit degree is as much below 32°F. as —5°C. is below 0°C. Since 100 Centigrade divisions are equal to 180 Fahrenheit divisions, 5 Centigrade divisions are equal to 9 Fahrenheit divisions; and hence the answer is 32 — 9, or 23°F.

Find the equivalent of —31°F. on the Centigrade

scale. Now, —31°F. means 63 Fahrenheit divisions below freezing point of water, or 7 times 5 Centigrade divisions below it; the answer is therefore —35°C.

Find 98°C. on the Fahrenheit scale. Now, 98°C. is 2 Centigrade divisions, or 3·6 Fahrenheit divisions below the boiling point of water; the answer is therefore 212 — 3·6, or 208·4°F.

Examples on the Thermometric Scales.

1. Find —40°C., —10°C., and 250°C. on the Réaumur and Fahrenheit scales.—*Ans.* —32°R., —8°R., 200°R.; —40°F., 14°F., 482°F.

2. Find —20°F., 20°F., and 120°F., on the Réaumur and Centigrade scales.—*Ans.* —23°R., —5·3°R., 39°R.; —28·9°C., —6.7°C., 48·9°C.

3. If, on a certain scale, 0°C. is denoted by the number 15°, and 100°C. by the number 120°, what numbers on this scale will denote 5°C., 10°F., 15°R., —20°C., —30°F., 60°F., and —40°R. respectively? *Ans.* 20·3°, 2·2°, 34·7°, —6°, —21·2°, 31·3°, —37·5°.

4. If, on a certain scale, —3°F. is denoted by —17°, and 1°F. by —12°, what numbers on this scale will denote —3°C., 60°R. and 40°F.? Also, what will be the freezing point and what the boiling point of water on this scale?—*Ans.* 20°, 195·5°, 36·8°; 26·8°, 251·8°.

There are several circumstances that render mercury particularly suitable for thermometrical purposes; amongst which we may here mention that it does not wet glass—*i.e.* when the mercury falls in the tube, particles of mercury do not adhere to the tube and remain

behind as water does. This non-adhesion to glass is accounted for by the fact that the different particles of mercury cohere with much greater force than that with which mercury adheres to glass; it accounts for the *meniscus* in the mercurial barometric column. Again, mercury, like other metals, is a remarkably good conductor of heat; for this reason it feels very cold to the hand when touched; hence, when heat is imparted to one portion of it, the whole becomes uniformly heated. Thirdly, mercury is liquid at all ordinary temperatures; it freezes a little above —40°C., and boils at 350°C. There are several other advantages possessed by the mercurial thermometer, which will be noticed when they will be understood. With all these circumstances in favour of the use of mercury, it is fortunate that the metal can be easily obtained in a pure state.

But, for certain purposes, the mercurial thermometer is utterly useless; for these purposes we have to use special kinds of thermometers. For example, the *Spirit Thermometer*, which is made in exactly the same way as the mercurial thermometer, is used for temperatures below —35°C. It is next to useless for high temperatures, as alcohol, the liquid contained in the tube, boils below 80°C.; but it is very serviceable for low temperatures, since it has never been frozen into a solid, whereas mercury freezes at —40°C.

Self-registering, or register thermometers are so constructed that they will indicate the highest or the lowest temperature attained by the thermometer during any given time, *e.g.* during the night. Such thermometers are employed when we wish to ascertain *the temperature* of water at great depths beneath the

surface. Rutherford's *maximum thermometer* has the shape given it in Fig. 13. A is a piece of steel that has been carried forward by the mercury, and has been left behind on the temperature falling. The end of A nearest the bulb marks the maximum temperature. The action of this instrument depends upon the fact that mercury does not wet steel; consequently when the mercury advances, it drives the steel before it. Rutherford's *minimum thermometer* has the same shape as the preceding, but it contains alcohol in the place of mercury, and a small rod of ivory, B, instead of one of steel. Alcohol adheres with great force to ivory; therefore, as the alcohol recedes in the stem, it carries

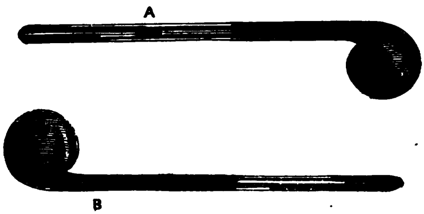

Fig. 13.

the ivory along with it; but, when the temperature becomes higher, the alcohol advances and leaves the ivory where it is. Hence that end of B which is furthest from the bulb indicates the lowest temperature attained by the thermometer. The steel and the ivory are replaced by agitation.

In future, all temperatures will be given on the Centigrade scale, unless the contrary is stated.

The immediate consequence of a liquid expanding is *that its relative* weight diminishes. For instance, if

1 litre of a liquid at 0° weighed 3 kilogrammes, and if this litre were heated to such a temperature that its volume became doubled, we should have, at this higher temperature, 2 litres weighing 3 kilogrammes—the same absolute weight as before, but double the volume, for heat does not destroy or in any way influence absolute weight. But the liquid at this higher temperature, though weighing exactly the same as at 0°, would still be relatively lighter; 2 litres would weigh 3 kilogrammes, and therefore 1 litre would weigh 1½ kilogrammes; whereas 1 litre at 0° weighed 3 kilogrammes. The liquid at the higher temperature is, *bulk for bulk*, lighter than the same liquid at 0°. We see that the volume of the liquid has been doubled, and the relative weight halved; if the volume had been trebled, the relative weight would have been ⅓ of the relative weight at 0°. If anything is completely immersed in water, it depends entirely upon its relative weight whether the thing sinks, floats, or remains where it is. If, as in the case of iron, its relative weight is greater than that of water,—*i.e.* if 1 cubic centimetre of it weighs more than 1 cubic centimetre of water at the same temperature—it is said to be heavier than water, by which is meant that any bulk of it is heavier than an equal bulk of water, and it will sink; if, on the other hand, as in the case of ice or common oil, its relative weight is less than that of water—1 cubic centimetre of it weighing less than 1 cubic centimetre of water at the same temperature—it will rise to the surface and float. When heat is applied from below to a liquid contained in a large flask, this process of rising to the surface takes place, and can be rendered evident by

adding some cochineal powder to the liquid. The liquid at the bottom of the flask becomes heated, expands, and consequently its relative weight becomes less than that of the liquid above it, through which, therefore, it rises as oil rises through water, and its place is supplied by the cold water from the surface. This process is evidently a continuous one until the whole of the liquid is at the same temperature, and the accompanying diagram (Fig. 14) represents the currents of liquid particles produced. The whole bulk of the liquid becomes heated, not by conduction, but through the agency of liquid particles that are themselves heated. The heat is distributed by being conveyed from one part of the liquid to another by heated particles; this process is therefore called *convection* of heat, and it is mainly by convection that liquids become heated through their entire bulk

Fig. 14.

when heat is applied to one portion of them. To prove that liquids have but little tendency to *conduct* heat, we must heat the liquid, not from below, but from above. A test tube, $\frac{3}{4}$ths filled with water, is placed above a lamp, so that the flame heats only the upper portion of the water; the water at the surface can be easily raised to near the boiling point, while that at

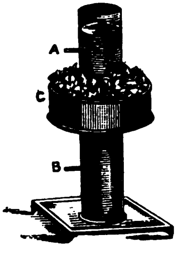

Fig. 15.

the bottom of the test tube is scarcely affected. If two delicate thermometers, A and B, are placed in a Hope's apparatus (Fig. 15), filled with water, and the tray C is filled with lumps of hot coal, the upper thermometer will indicate that its temperature has been raised long before the lower one undergoes any perceptible change. Mercury is an exception to what has just been said; like other metals, it is a good conductor of heat, and hence we must not use mercury in order to prove that liquids are usually bad conductors. The convection of heat by liquids is employed on a large scale as a means for warming houses, hospitals, &c.

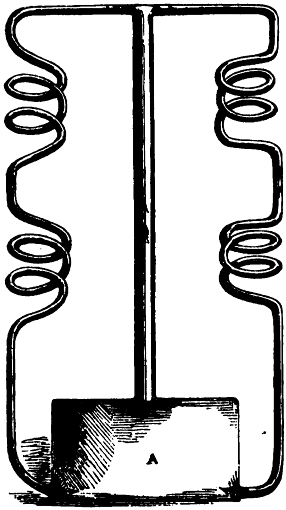

Fig. 16.

Figure 16 will show the general arrangement adopted. A large boiler (A) in the lower storey of the house is connected with pipes that branch in the suitable directions upwards, and surround the rooms to be warmed. At the top of the house, the pipes are either closed *or open into* a cistern. The whole arrangement is

filled with water, which, when heated at A, takes the course indicated by the arrows, and, having imparted heat to the rooms around which it circulates, it returns to the boiler, where it is again heated. The same phenomenon can be exhibited on a small scale in the following manner:—A rectangle of glass tube, A B C D (Fig. 17) is obtained, and a heavy coloured liquid is poured into it at E, so as to fill the shaded part, B C; by careful manipulation, the rest of the tube can be filled with water without disturbing the coloured liquid to any very great extent. E is now closed by means of a cork, and heat is applied at F. After a few seconds, the whole liquid begins to circulate round the rectangle, and the heavy-coloured liquid rises from C to D, and gradually mixes with the water. After a short interval, if the hand is passed along the tube,

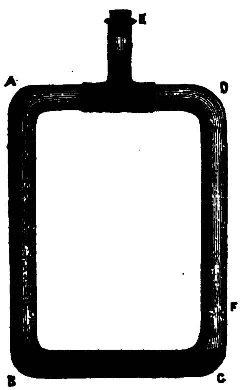

Fig. 17.

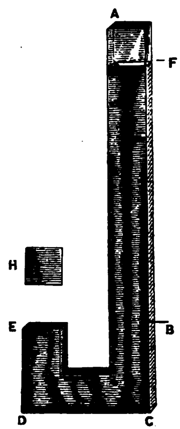

Fig. 18.

from F to D, from D to A, and so on, the tube will be found to be very hot at F, and to get colder and colder as we pass in the direction of the liquid current, until, at C, the tube is scarcely warmer than it was before the heat was applied.

Cooling a liquid at its surface has practically the same effect as heating it from beneath. The surface water of a lake in cold weather contracts and consequently sinks through the warmer and relatively lighter particles of water that are beneath the surface. A stream of heavy liquid particles may be seen to fall from a piece of ice floating in tepid water.

The effect of temperature upon a barometer can now be easily understood. A barometer is an instrument for determining the weight or pressure of the atmosphere. In order to render the principle of this instrument the more clear, suppose a tube (Fig. 18)—the sectional area of which is square—to be completely filled with mercury. H stands for the cross section of the tube at any part, and we will suppose its area to be 1 square centimetre; A C is about 1 metre long, and is closed at A, and E D about 1 decimetre long, and open at E. But, when the tube is placed as in the figure, it does not remain full of mercury; the mercury falls from A to a point F about 7·6 decimetres above the level (B) of the liquid in E, and a quantity of mercury consequently flows out of the tube at E. The portion of the tube now occupied by the mercury is F C D E. The mercury in E D balances or supports the mercury in B C; but the mercury in F B is balanced by the pressure or weight of the atmosphere. The barometer is *nothing* more than a balance turned, as it were, upside

down; the equal arms of the balance are acted upon by the weight of the atmosphere and the weight of the mercury; and, as these two weights balance each other, they must be equal (Fig. 19). Now by the weight of the atmosphere in this case we mean the weight of a column of air 1 square centimetre in sectional area and extending from the level B E to the upmost limit of the atmosphere (70 or 80 kilometres high).

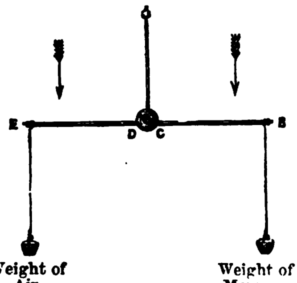

Fig. 19.

Such a column of air is pressing upon the mercury at E, and this pressure supports a similar column of mercury 7·6 decimetres or 76 centimetres high. The weight of the air column is equal to the weight of the mercury column. Now a column of mercury, 76 centimetres high and 1 square centimetre across, measures in all 76 cubic centimetres; and each cubic centimetre of mercury at 0° weighs 13·596 grammes; therefore the whole column weighs (13·596 × 76) or 1033·3 grammes or 1·0333 kilogramme. Hence the weight of the column of air 1 square centimetre across is also 1·0333 kilogramme; in other words, the pressure of the air on the square centimetre is 1·0333 kilogramme. The mercury is not always at the same height in the tube A C, partly because the air does not always press with the same force; but we will not at present concern ourselves *with variations* of atmospheric pressure. Let us

suppose that the air continues to exert a pressure of 1·0333 kilogramme on the square centimetre.

It will be observed that we have been compelled to consider the *temperature* of the mercury, for at no other temperature than 0° does 1 cubic centimetre of mercury weigh 13·596 grammes. Mercury expands when heated, becomes relatively lighter, and consequently 1 cubic centimetre of mercury weighs less at 15° than at 0°; and therefore a higher column of mercury is required to balance the atmospheric pressure at 15° than at 0°. The same end cannot be attained by making the tube A C broader, say 2 square centimetres across; for 76 centimetres height of mercury at 0° in such a tube would weigh twice 1·0333 kilogramme, and hence the pressure *on the square centimetre* would not be doubled but would remain the same; in fact, the whole tube A C D E may vary as much as we please in cross section, and still the mercury will remain at the same height, if only the atmospheric pressure remains constant and the temperature remains the same. But if the temperature rises, the mercurial column also rises; if the temperature falls, the mercurial column also falls.

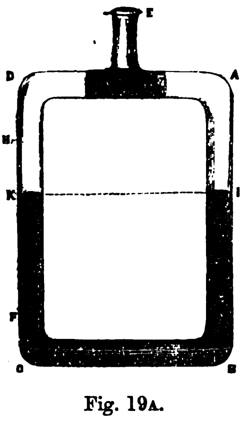

Fig. 19A.

This can be proved by means of the rectangle of glass tube above mentioned. Part of the coloured liquid is poured out of the tube, so that what remains

shall occupy a portion I B C K of the tube (Fig. 19A). I and K are at the same level in whatever position we hold the tube; and, if the part C D of the tube is twice as broad across as the part A B, we know that the liquid in the broad part will rise as high as that in the narrow part. Now, if the liquid is heated at F, we know by the previous experiment that practically only the part F K of the liquid becomes heated, while the rest of the liquid remains at very nearly the same temperature; as F K becomes hotter, the liquid is observed to rise above the level I K to a certain point, say H, when it begins to boil; but the liquid in A B is at very nearly the same temperature as before, and has not undergone any perceptible change of level. Hence the *weight* of liquid, I B, remains practically constant throughout the experiment, and balances the liquid in the other leg; hence the weight of the liquid in this latter leg also is constant throughout, although the height of the liquid varies with the temperature. Now it is clear that the cold liquid is relatively as much heavier than the hot liquid as the column of the hot liquid is higher than the column of the cold liquid; for instance, if the hot liquid column is 1 metre high, and the cold liquid column only ·5 metre high, the bulk of cold liquid weighs the same as twice the bulk of hot liquid, *i.e.* weighs twice as much as an equal bulk of the hot liquid; in other words, the cold liquid is relatively twice as heavy as the hot liquid. If the cold liquid is ·5 metre high and the hot liquid ·51 metre high, the hot liquid is $\frac{\cdot 51}{\cdot 5}$ or 1·02 times higher than the cold liquid, and therefore the cold liquid is 1·02 *times* heavier than the hot liquid.

If we keep the cold liquid at some fixed temperature,

say 0°, we can in this way find out how much h
it is than the same liquid at higher temperatures
for example, we had two barometers, one of whic
kept at 0° and the other at some higher tempera
and if we observed that the mercury in the cold
meter was ·76 metre high, while that in th
barometer was ·762 metre high (*i.e.* $\frac{\cdot 762}{\cdot 76}$ or 1·(
times higher than the cold mercury)—we should a
know that the cold mercury was 1·00263 times h
than the hot mercury. Observations of this kind
been made by Dulong and Petit, and afterwards
accurately by Regnault (*b.* 1810); but, as Dulon
Petit's method is the simpler to understand, w
confine ourselves to that alone.

Instead of two barometers, Dulong and Petit u
sort of double baron
represented in Fig
one leg of which wa
at 0° by means of a
filled with ice, whi
other leg was heat
to some known tem
ture by a hot oil
The apparatus w
arranged that the
levels of the m
could be just see
would not do to ha
upper levels too far out of their respective
since the portions outside the baths are not at e
the same temperatures as those inside the

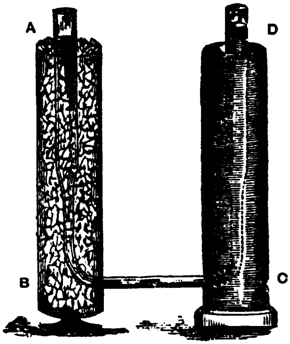

Fig. 20.

The heights of the columns were observed through a sort of telescope called a *Cathetometer*. The utmost accuracy is required in these observations, since the difference between the levels in the two tubes is not great, and a small inaccuracy in the observations of the heights makes a very great difference in the relative weights deduced from those heights. For instance, if the height A B is ·253 metre and the height D C is made out to be ·256 instead of ·2555, we deduce from this that the cold mercury is $\frac{\cdot256}{\cdot253}$ or 1·011858 times heavier, instead of $\frac{\cdot2555}{\cdot253}$ or 1·013834 times heavier than the cold mercury. By this method it was found that, if A B is 1 decimetre high at 0°, D C is 1·018153 decimetre high at 100°, *i.e.* 1·018153 times higher. Hence mercury at 100° is 1·018153 times lighter than mercury at 0°, bulk for bulk. Now a cubic centimetre of mercury at 0° is known to weigh 13·596 grammes, and 1·018153 times lighter than this is $\frac{13\cdot596}{1\cdot018153}$ or 13·35359 grammes, which is therefore the weight of 1 cubic centimetre of mercury at 100°. In other words, the relative weight of mercury at 0° being 13·596, the relative weight at 100° is 13·35359 nearly.

If we were to take 1 cubic centimetre of mercury at 0°, *i.e.* 13·596 grammes of it, and heat it to 100°, it would expand to a certain, and as yet unknown, extent, and all that we are sure of is, that at 100° our cubic centimetre occupies more than its former volume, *i.e.* more than a cubic centimetre, and that at 100° a cubic *centimetre weighs* 13·35359 grammes. But the cubic *centimetre at 0° has* lost no weight by being heated;

hence (13·596 — 13·35359) gramme is the weight of whatever bulk it occupies at 100° over and above the 1 cubic centimetre, which weighs 13·35359 grammes. The cubic centimetre at 0° has expanded to a cubic centimetre and something else; the former weighs 13·35359 grammes, the latter ·24241 gramme; hence we can find what increase of volume the mercury has undergone:—

Since 13·35359 grammes is the weight of 1 cub. cent. of mercury at 100°

$$\therefore \quad 1 \text{ gramme} \quad ,, \quad \frac{1}{13 \cdot 35359} \quad ,, \quad ,,$$

$$\text{and } \cdot 24241 \quad ,, \quad ,, \quad \frac{\cdot 24241}{13 \cdot 35359} \quad ,, \quad ,,$$

$$= \cdot 018153 \quad ,, \quad ,,$$

That is, 1 cubic centimetre of mercury at 0° expands when heated to 100° by ·018153 cubic centimetre, and *any* volume of mercury at 0° (as 1 litre) expands when heated to 100° by ·018153 of *that* volume (as ·018153 litre). This result, it will be seen, has been deduced from observations which are wholly independent of the expansion of the containing vessels; and this, therefore, is the solution of the problem set forth at the commencement of this chapter, namely, the determination of the absolute expansion of a liquid.

The amount of expansion undergone by the mercury can be deduced much more simply than in the way shown above. Suppose A B to be 1 square centimetre across and 1 decimetre or 10 centimetres high at 0°; then the liquid occupies at 0° a volume of 10 cubic centimetres. The same weight of liquid at 100° occupies a volume of 10·18153 cubic centimetres, if D C is supposed to be 1 square centimetre across, as its

height is observed to be 1·018153 decimetre or 10·18153 centimetres. That is, the 10 cubic centimetres expand by ·18153, or 1 cubic centimetre expands by the tenth part of ·18153 or ·018153 of a cubic centimetre.

The absolute expansion of mercury has been determined not only between 0° and 100°, but also between 0° and many other temperatures, and the following table shows some of the results obtained :—

	1 cubic centimetre of mercury		at	0°
becomes	1·001792 cub. cent.		,,	10°
	1·003590	,,	,,	20°
	1·005393	,,	,,	30°
	1·007201	,,	,,	40°
	1·009013	,,	,,	50°
	1·010831	,,	,,	60°
	1·012655	,,	,,	70°
	1·014482	,,	,,	80°
	1·016315	,,	,,	90°
	1·018153	,,	,,	100°
	1·036811	,,	,,	200°
	1·055973	,,	,,	300°
	1·065743	,,	,,	350°

The amount of expansion for 10 Centigrade degrees is ·001792, and hence the mean or average expansion between 0° and 10° is ·0001792, or the tenth part of ·001792. In the same way the average expansion
between 0° and 20° is 1-20th of ·00359 or ·0001795,
,, 0° and 30° is 1-30th of ·005393 or ·00017976,
and so on. By this we see clearly that mercury does not expand so much from 0° to 1° as from 1° to 2°; in fact that the rate of expansion gets faster and faster as *the temperature* rises. The average rate of expansion *between 0° and 20°* is ·0001795, but between 0° and

100° it is ·00018153. Now the amount by which any volume of a liquid expands when heated from 0° to 1° is called the *coefficient of expansion* of that liquid. The average or mean coefficient of expansion of mercury between 0° and 10° is ·0001792; by which is meant that 1 cubic centimetre or 1 cubic decimetre, &c., of mercury at 0° becomes, when heated to 10°, 1 cubic centimetre or 1 cubic decimetre, &c., + ten times ·0001792 of the volume at 0°, *i.e.* 1·001792 cubic centimetre or 1·001792 cubic decimetre, &c. 3 cubic centimetres at 0°, when heated to 30°, become three times as much in volume as 1 cubic centimetre; but 1 cubic centimetre becomes 1 cubic centimetre + 30 times ·00017976 or 1·005393 cubic centimetre, and therefore 3 cubic centimetres become three times 1·005393, *i.e.* 3·016179 cubic centimetres at 30°.

Questions on Expansion of Mercury.

1. Find the mean coefficients of expansion of mercury between 0° and 70°, and between 0° and 350°; also between 20° and 30°, and between 50° and 80°, and between 100° and 200°.—*Ans.* ·00018078; ·00018784; ·000179655; ·00018067; ·00018325.

2. From the table given above, find the relative weight of mercury or the absolute weight of 1 cubic centimetre of mercury at 10°, 40°, 80°, and 300°.—*Ans.* 13·5717; 13·4988; 13·4019; 12·8753.

3. Having given the mean coefficient of expansion of mercury between 0° and 150° as ·00018279, find the volume at 150° of 3·6 cubic centimetres of mercury measured off at 0°.—*Ans.* ·0037 litre very nearly.

given the mean coefficient of expansion

of mercury between 0° and 130° as ·00018228, and between 0° and 160° as ·00018304, find the increase of volume undergone by 30 cubic centimetres of mercury when heated from 130° to 160°, and the diminution of volume undergone by 50 cubic centimetres when cooled from 160° to 130°.—*Ans.* ·16 cubic centimetre; ·27 cubic centimetre.

5. 1·15 litre of mercury measured off at 0° occupies at 220° a volume of 1196·69345 cubic centimetres. Deduce from this the mean coefficient of expansion of mercury between 0° and 220°.—*Ans.* ·00018456.

By referring back to the determination of the cubical expansion of solids, it will be seen that the methods there described presupposed a knowledge of the absolute expansion of mercury, or of the relative weight of mercury or of some other liquid at different temperatures.

The *apparent* expansion of mercury varies with the nature of the vessel used, and is less in proportion as the vessel is more expansible; with glass vessels the coefficient of apparent expansion between 0° and 100° is about ·0001545. As we now know the absolute, as well as the apparent expansion of mercury, we can deduce the cubical expansion of the containing vessel; and by merely observing the apparent expansion of other liquids in this vessel, and correcting for the cubical expansion of the vessel, we can at once obtain the absolute expansion of the liquids without again having recourse to Dulong and Petit's apparatus.

Liquids that boil at a low temperature expand more rapidly at ordinary temperatures than those which boil at a higher temperature; for example—

		Mean coefficient of expansion between 0° and 10°	40°	80°
Ether boils at	35°	·00152	·00667	
Alcohol	78·4°	·00105	·00440	·00974
Water	100°		·00075	·00286
Mercury	350°	·000179	·00018	·00018

We now see how regularly mercury expands compared with alcohol, and therefore why mercury is much better fitted than alcohol for ordinary thermometrical purposes; but it must be remembered that the temperature is measured, not by the absolute, but by the apparent expansion of these liquids—by the excess of their expansion over that of the glass tube. In the above table it is seen that, with other liquids besides mercury, the rate of expansion increases with the temperature. By special methods, liquids can be heated to a great distance above their boiling points without boiling, and under these circumstances the rate of expansion goes on rapidly increasing just as it did below the boiling point.

6. If a barometer stands at 760 millimetres when at 0°, what will be the height of the column at 20°?—*Ans.* ·7627 metre.

7. The height of the mercurial column of a barometer is ·761 metre at 10°. Reduce this to 0°.—*Ans.* 759·6 millimetres.

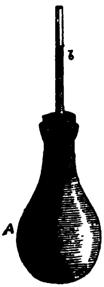

Fig. 21.

An apparatus similar to the one represented in Figure 21 can be employed to show the behaviour of water with respect to heat. A is a flask completely filled with pure water; this flask is provided with a cork, through which passes a capillary tube;

the water fills this capillary tube to the point *b*, and above this point there are a few drops of a solution of iodine in ether, which serves to make the upper level of the water visible. The water is now at the ordinary temperature of the air; but, if it is put into a beaker and surrounded with snow or ice, the temperature of the water gradually falls, the bulk of the water gradually diminishes, and consequently the opaque drops of iodine solution are observed to fall in the capillary tube. This fall of the water column goes on until the temperature of the water is 4°; but, on still further cooling, the water expands, and the iodine solution rises in the tube. By special methods, water can be cooled below its freezing point (0°) without passing into the solid state, and it is found that it goes on expanding from 0° to —1°, from —1° to —2° and so on, just as it did from 3° to 2°, and from 2° to 1°. Water is said to occupy its least volume at 4°, because it expands and occupies a greater volume whether it be heated above that temperature or cooled below it. It has been found that water expands to very nearly the same extent whether it is heated above 4° or cooled below that temperature for a certain given number of degrees; thus, if water at 4° is heated to 5°, it expands about as much as if it had been cooled to 3°; and the same may be said of 6° and 2°, of 7° and 1°, and so on; but it will be seen below that the expansion is rather more rapid with diminution than with increase of temperature, and that, when cooled below 0°, water expands very rapidly indeed.

The following table will show the bulk at different *temperatures of 1* cubic centimetre of water measured *off at 4°:—*

Temperature.	Volume in Cubic Centimetres.
—9°	1·0016311
—5°	1·0006987
—4°	1·0005619
—3°	1·0004222
—2°	1·0003077
—1°	1·0002138
0°	1·0001269
1°	1·0000730
2°	1·0000331
3°	1·0000083
4°	1·0000000
5°	1·0000082
6°	1·0000309
7°	1·0000708
8°	1·0001216
9°	1·0001879
10°	1·0002684
50°	1·01205
100°	1·04315
131°	1·07435
157°	1·10168

The weight of 1 cubic centimetre of water at 4° is 1 gramme; and, since the relative weights of solids and liquids are generally taken at 0°, and compared with water at 4°, we never have any difficulty in finding the weight of any bulk of a liquid or of a solid at 0°, providing we know its relative weight. For instance, if we are told that 13·596 is the relative weight of mercury at 0°, we know that 1 cubic centimetre of *mercury measured* off at 0° weighs 13·596 grammes, or 13·596 *times* as much as 1 cubic centimetre of

water at 4°. When discussing the cubical expansion of solids, we explained a method by means of which we could determine the amount of expansion undergone for any increase of temperature by ascertaining the relative weight of the solid at each temperature. It will be seen, on referring back to that chapter, that the relative weight was in all cases given with water at 4° as the standard of comparison. But, since the relative weight of a solid at, say, 15° is found by weighing it in water, we really find how much heavier it is than an equal bulk of water at 15°. Hence, in order to find the true relative weight of the solid (*i.e.* as compared with water at 4°), it is necessary to be able to find the relative weight of water at different temperatures.

The relative weight of water at any temperature given in the foregoing table can be deduced from the data before us.

Examples on Relative Weight of Water.

1. What is the relative weight of water at 7°?—From the table we see that 1·0000708 cubic centimetre of water at 7° will contract to 1 cubic centimetre at 4°, and will therefore weigh 1 gramme; hence 1 cubic centimetre at 7° weighs $\frac{1}{1{\cdot}0000708}$ or ·999929 gramme. Hence the relative weight of water at 7°, as compared with water at 4°, is ·999929.

2. Find the relative weight of water at 1°, 10°, and 100°.—*Ans.* ·999927; ·999731; ·958634.

3. What is the weight of 1 litre of water at 10°, *and of 1·3 litre* of water at 50°?—Ans. 999·731 *grammes; 1·2845209* kilogramme.

4. At what temperature approximately must water be measured off in order that 1·1 litre of it shall weigh 1·099966 kilogramme?—*Ans.* 2°, or 7°.

If the relative weight of a solid at 100° (as compared with water at 100°) is 12, 1 cubic centimetre of the solid at 100° weighs twelve times as much as 1 cubic centimetre of water at 100°, *i.e.* $12 \times \cdot 958634$, or 11·503608 grammes; but this is the weight of 11·503608 cubic centimetres of water at 4°, and therefore the true relative weight of the solid at 100°, *i.e.* as compared with water at 4°, is 11·503608.

5. The relative weight of a solid at 50°, as compared with water at 50°, is 10. Find its relative weight as compared with water at 4°.—*Ans.* 9·88093.

6. The relative weight of a solid at 50°, as compared with water at 50°, is 6. Find its relative weight as compared with water at 10°.—*Ans.* 5·93.

When any large body of water, as a lake, is exposed to a cold atmosphere, the surface water cools and, becoming denser, sinks to the bottom, being replaced by the warmer water from beneath, as has been already explained. This process goes on until the whole of the water is at a temperature of 4°. If the surface water is now cooled to 3°, it expands and remains at the surface; and so the temperature of the surface may fall to the freezing point while the water beneath the surface is not much below 4°; for, as we know, water is a very bad conductor of heat, and therefore a long and severe frost is necessary to freeze water to any considerable depth. If water went on contracting below 4°, the temperature of the whole lake would be *reduced to 0°* before the surface water would freeze;

as it is, the freezing water, as well as the frozen water, serves as a covering to the rest of the lake.

But the above observations do not apply to sea water, which contains a large quantity of salts in solution. With sea water, the maximum relative weight is at —3·7°, and it freezes a very little above —2°. So that a salt-water lake would be at about —2° throughout its whole depth when the surface was frozen; but the ice formed is lighter than the water, and would therefore remain at the surface and prevent the rest of the water from becoming much colder. There are several circumstances that prevent the sea from freezing; amongst which may be mentioned the great bulk of water to be cooled and its rapid motion from one climate to another, and also the low temperature required (—2°). But in the Arctic regions, the sea does freeze.

Miscellaneous Examples.

1. A piece of ice is forcibly kept at the bottom of a beaker, and the latter is then filled with water at 15°. Describe accurately the changes which the water undergoes with respect to temperature.

2. In the preceding question, state clearly what difference (if any) it will make if the ice is in the middle, instead of at the bottom, of the water.

3. In the experiment on p. 45 show why the current of liquid is not *up* by the sides of the vessel and *down* the middle of it.

4. When hot water is poured into a glass already half filled with milk, it is often noticed that the mixture at the top is very much hotter than that at the bottom *of the glass.* Explain this.

CHAPTER V.

EXPANSION OF GASES.

It will be remembered that, when solids and liquids expand, the heat which causes them to expand has to overcome several forces—one of which is cohesion—and that these forces have a far greater influence upon the bulk of solid and liquid bodies than the pressure of the atmosphere has. If a solid or a liquid body is placed beneath the receiver of an air-pump, and if the air is then withdrawn from it, the change in bulk undergone by the solid or by the liquid is perfectly imperceptible. But it is very different with gases; a gas will expand to almost any extent if the external pressure upon it is removed. If a bladder half filled with air is placed in the exhausted receiver of an air-pump, it will swell out, and perhaps burst. The pressure of the atmosphere is not constant; sometimes it will support a column of mercury 760 millimetres high, sometimes more, sometimes less. But the normal or average pressure is taken to be 760 millimetres of mercury at 0°. In all that we say of gases, we will suppose them to be under the normal pressure unless the contrary is specially stated. It must be remembered that, if a certain bulk of gas is measured off when the barometer is at 760 millimetres, its bulk will be greater if the barometric column falls, and less if the column rises.

Gay-Lussac* was the first to investigate the expansion of gases with any great degree of accuracy; after him, Dulong and Petit. The instrument used (Fig. 22) was like a thermometer which was partly filled

Fig. 22.

with the pure gas ; a drop of mercury, M, served to separate the gas from the external air and to indicate its volume. The capacity of the bulb and of each division of the graduated stem was accurately determined, so that the whole volume of the gas could be easily deduced from the position of the mercury. The bulk of the enclosed air at 0° was ascertained by cooling the instrument to 0°, and observing the position of the mercury in the tube; the air was then heated to several higher temperatures, and its volume at each of these was recorded. Gay-Lussac found that, if a litre of air was measured off at 0°, and if it was then heated to 100°, it occupied 1·375 litre; so that the amount of expansion between 0° and 100° was ·375. This would give the mean or average coefficient of expansion as ·00375. We spoke of the mean coefficient of mercury; between 0° and 100°, it was ·0001815, very much less than the mean coefficient for air as determined by Gay-Lussac. It is true that 1 litre of mercury at 0° becomes 1·01815 litre at 100°, but it is not true that 1 litre at 0° becomes 1·0001815 at 1°, and 1·001815 litre at 10°, and so on. Mercury expands

* *Louis Joseph* Gay-Lussac (1778—1850).

less rapidly at low than at high temperatures; the coefficient of expansion of mercury is less than ·0001815 at 0°, and becomes gradually greater and greater till, between 60° and 100°, it is greater than ·0001815. The number ·0001815 is really only an average coefficient. Gay-Lussac, however, ascertained that, in the case of gases, the average or mean coefficient of expansion is also the true coefficient of expansion, and that a gas continues to expand to the same extent from 0° to 1°, from 3° to 4°, from 50° to 51° and so on. With gases, the mean coefficient between 0° and 10° is the same as the mean coefficient between 0° and 50°, or between 0° and 100°. The number ·00375, however, is not the correct coefficient for air; Rudberg deduced the number ·003648; and, lastly, Regnault made several series of very accurate experiments on the expansion of gases generally, and deduced, for air, the number ·00367, which is now usually adopted.

Gas.	Coefficient of Expansion.
Air	·00367
Hydrogen	·003661
Carbonic oxide	·003669
Carbonic acid	·003710
Nitrous oxide	·003719
Sulphurous acid	·003903
Cyanogen	·003877

It was observed by Dalton* and Gay-Lussac (and the observation has been corroborated by subsequent researches) that all gases have practically the same coefficient of expansion. We see that it is true of

* *John* Dalton (1766—1844).

air, hydrogen, and carbonic oxide; the exceptions—carbonic acid, &c.—are only apparent, as will be seen further on. Very important, as assisting in the elucidation of these exceptions, are the experiments of Regnault; who determined the coefficients of expansion of air and other gases, when under greater pressure than that exerted by the atmosphere. The following table gives some of his results:—

Coefficient of expansion of air under a pressure of

760	millimetres	is	·00367
2525	,,		·003694
2620	,,		·003696

Coefficient of expansion of hydrogen under a pressure of

760	millimetres	is	·003661
2545	,,		·0036616

Coefficient of expansion of carbonic acid under a pressure of

760	millimetres	is	·00371
2520	,,		·003845

Coefficient of expansion of sulphurous acid under a pressure of

760	millimetres	is	·003903
985	,,		·003984

It will be seen hereafter (page 116) how these results clear up the apparent exceptions to the law that all gases have practically a uniform rate of expansion, and *not specific expansibilities* as was found to be the case with solids and liquids. In the meantime, it is important to remember the fact that the coefficient of *expansion is greater* when the gas is subjected to great

pressure. From the meaning of the term "coefficient of expansion," it will be at once seen that 1 litre of hydrogen at 0° becomes, at 1°, (1 + ·00366) litre; at 2°, 1 + twice ·00366, or (1 + ·00732) litre; at 3°, 1 + three times ·00366, or (1 + ·01098) litre, and so on. Hence 5 litres of hydrogen at 0° become five times (1 + ·00732) litre at 2°; and five times (1 + ·01098) litre at 3°, and so on. These results can be thus tabulated:—

Temperature.		Bulk of 1 litre of hydrogen measured off at 0°.
0°	....	1 litre
1°	....	1 + ·00366
2°	....	1 + ·00366 + ·00366
3°	.. ..	1 + ·00366 + ·00366 + ·00366

Conversely, if it be required to find the bulk at 0° of any volume of a gas measured off at some higher temperature, say 3°, we proceed from the known fact that 1 litre of that gas at 0° becomes, at 3°, 1·01098 litre, or (1 + 3 × coeff. of expansion) litre. What is the bulk, at 0°, of 5 litres of hydrogen measured off at 3°? Now, since 1 + three times ·00366, or

(1 + ·01098) litre of hydrogen at 3° becomes 1 litre at 0°, it follows that

$$\text{1 litre of hydrogen at 3° becomes } \frac{1}{1+{\cdot}01098} \text{ litre at 0°.}$$
$$= {\cdot}989 \text{ ,, at 0°.}$$
$$\text{or 989 cub. cent. at 0°.}$$
$$\therefore \text{5 litres ,, ,, become } 5 \times 989 \text{ ,, at 0°.}$$

If such a question as this is asked—What is the bulk at 20° of 10 litres of hydrogen measured off at 30°?—it will be seen that there are two known facts by

means of which we may arrive at the answer. These two facts are that

1 litre of hydrogen at 0° becomes (1 + thirty times ·00366) litre at 30°,

and that

1 litre of hydrogen at 0° becomes (1 + twenty times ·00366) litre at 20°;

but we do not know from the coefficient of expansion of hydrogen what is the volume at 20° of 1 litre measured off at 30°. Hence there are two separate calculations to make; the first is to find the volume at 0° of the gas that was measured off at 30°, and the second is to find the volume of this gas when heated from 0° to 20°.

∵ (1 + 30 × ·00366) litre of hyd. at 30° becomes 1 litre at 0°.

∴ 1 " " " " $\frac{1}{1+\cdot 1098}$ litre at 0°.

= ·901 cub. cent. at 0°.

∴ 10 " " " become 9·01 litres at 0°.

Again,

∵ 1 litre of hydrogen at 0° becomes (1 + 20 × ·00366) litre at 20°.

= (1 + ·0732) litre at 20°.

∴ 9·01 litres " " become (9·01 × 1·0732) litres at 20°.

= 9·6695 litres at 20°.

It will be seen that (1 + twenty times ·00366) litre at 20° becomes (1 + thirty times ·00366) litre at 30°, or (1 + ·0732) litre at 20° becomes (1 + ·1098) litre at 30°. And we may start from this one fact, which is only a combination of the two facts above given. Thus:

$\because$ 1·0732 litre at 20° becomes 1·1098 litre at 30°.

$\therefore \dfrac{1{\cdot}0732}{1{\cdot}1098}$ " " 1 "

$\therefore \dfrac{10{\cdot}732}{1{\cdot}1098}$ " " 10 "

that is, 10 litres at 30°, if cooled to 20°, occupy a volume of $\dfrac{10{\cdot}732}{1{\cdot}1098}$, or 9·6695 litres. The following examples should be worked out in *both* ways, by using the coefficients of expansion given above. For ordinary purposes, ·00366, or 1–273rd may be used for all gases.

Examples on Expansion of Gases.

1. 15 litres of carbonic acid are collected at 25°; what will be the volume of the gas at 0°?—*Ans.* 13·727 litres.

2. 20 litres of nitrous oxide are collected at 0° ; what will be the volume of the gas at 25°?—*Ans.* 21859·5 cubic centimetres.

3. 200 cubic centimetres of sulphurous acid are collected at 15°; what will be the volume of the gas at 100°?—*Ans.* ·2627 litre.

4. An empty vessel, the temperature of which is 300°, has to be filled with carbonic oxide; the capacity of the vessel is 30100 cubic centimetres; what bulk of carbonic oxide at 15° must be passed into the vessel in order that the latter may be filled with the gas at 300°? —*Ans.* 15·8727 litres nearly.

5. What diminution in volume takes place when 30

litres of air are cooled from 100° to 80°?—*Ans.* 1611 cubic centimetres.

6. What increase in volume takes place when 40 litres of cyanogen are heated from 10° to 12°?—*Ans.* 299 cubic centimetres nearly.

7. A room is 40 cubic metres in capacity; what bulk of air (measured off at 0°) is driven out of the room when its temperature is raised from 15° to 20°? —*Ans.* 648·129 litres nearly.

8. To what temperature must air (measured off at 0°) be raised in order that its volume may be increased by one half of its original volume?—*Ans.* 136·2°.

9. 1 litre of air is measured off at 0°; at what temperature is its volume equal to 2 litres?

1 litre at 0° expands by	·00367 litre when heated to				1°
and by twice	·00367	,,	,,	,,	2°
and by	$\frac{1}{\cdot 00367} \times \cdot 00367$	,,	,,	,,	$\left(\frac{1}{\cdot 00367}\right)^\circ$
i.e. by	1	,,	...	...	273°

therefore 1 litre at 0° becomes 2 litres at about 273°. This fact is more plainly seen if we consider that ·00367 is equal to $\frac{367}{100000}$ or $\frac{1}{273}$. Hence

$$1 \text{ litre at } 0^\circ \text{ becomes } 1 + \frac{1}{273} \text{ at } 1^\circ$$

$$\text{and } 1 + \frac{2}{273} \text{ at } 2^\circ$$

$$\text{and } 1 + \frac{3}{273} \text{ at } 3^\circ$$

$$\text{and } 1 + \frac{273}{273} \text{ at } 273^\circ$$

10. What bulk of air at 0° must be taken in order that, when heated to 1°, its volume shall be increased by 1 litre?—*Ans.* 272479·6 cubic centimetres.

11. 10 litres of air at 15° are heated until the volume of the air has become 12 litres; to what temperature has the air been heated?

∵ (1 + 15 times ·00367) litre of air at 15° becomes (1 + 16 times ·00367) litre at 16°

i.e. 1·05505 litre of air at 15° becomes 1·05872 litre at 16°

$$\therefore 1 \quad ,, \quad ,, \quad \frac{1{\cdot}05872}{1{\cdot}05505} \quad ,,$$
$$= 1{\cdot}0034785 \quad ,,$$

Hence 1 litre of air at 15° increases by ·0034785 litre when heated to 16°, and by twice ·0034785 when heated to 17°, and by three times ·0034785 when heated to 18°, and so on. Now the increase of volume given in the question is that of 2 litres on 10 litres, which is the same as an increase of ·2 litre on 1 litre.

Now, as ·0034785 litre is the increase for a rise of one degree of temperature

$$\therefore \quad 1 \text{ litre is the increase for a rise of } \left(\frac{1}{\cdot 0034785}\right) \text{ degrees.}$$

$$\text{and } \therefore \cdot 2 \text{ litre} \quad ,, \quad ,, \quad \frac{\cdot 2}{\cdot 0034785} \quad ,,$$
$$= \quad 57{\cdot}5 \quad ,,$$

Therefore the air must be heated 57½° above its original temperature; that is, to (15 + 57½)° or 72·5°.

12. 15 litres of air at 10° were heated to such a temperature that the volume increased by 1·5 litre; to what temperature was the air heated?—*Ans.* 38·2°.

13. 5 litres of air at 15° are cooled to a certain temperature, and the volume at that temperature is ob-

served to be 3·5 litres; to what temperature has the air been cooled?

$\because$ (1 + 15 × ·00367) litre of air at 15° becomes (1 + 14 × ·00367) litre at 14°

i.e.	1·05505	,,	,,	1·05138	,,
$\therefore$	1	,,	,,	$\frac{1 \cdot 05138}{1 \cdot 05505}$	,,
				= ·996521	,,

Hence 1 litre of air at 15° diminishes in bulk by (1 — ·99652) or ·003479 litre for each degree that it is cooled below 15°. Now, in the question, there is a diminution of volume from 5 litres to 3·5; this is equivalent to 1 litre contracting to $\frac{3 \cdot 5}{5}$ or ·7 litre, or to a diminution of ·3 litre for each litre of gas cooled. Now since—

·003479 litre is the diminution of volume for 1 degree.

$\therefore$	1	,,	,,	,,	$\left(\frac{1}{\cdot 003479}\right)$ degrees.
$\therefore$	·3	,,	,,	,,	$\left(\frac{\cdot 3}{\cdot 003479}\right)$,,
					= 86 degrees nearly.

Hence the air has been cooled to 86 degrees below its original temperature, that is, to (15 — 86)° or —71°.

14. 20 litres of carbonic oxide at 25° occupy a volume of 15·5 litres at a low temperature; find this latter temperature.—*Ans.* —41·9°.

The student should continually revert to the preceding examples until he has gained a complete mastery over them, because they are examples of a subject rarely comprehended by beginners. He may be able to simplify many of them by the use of the fraction $\frac{1}{273}$ in lieu of the decimal ·00366. The above examples are

exactly similar to sums in simple interest. Thus, taking the coefficient of expansion of air as $\frac{1}{273}$, *i.e.* $\frac{100}{273}$ per cent., the question—What is the volume at 20° of 10 litres of air measured off at 15°?—is exactly similar to the following:—A certain sum of money was deposited in a bank at $\frac{100}{273}$ per cent. per annum simple interest; at the end of 15 years, the principal and interest together (*i.e.* the *amount*) was found to be £10: what would be the amount at the end of 20 years after depositing the principal? In such a question as the following:—10 litres of air are measured off at 15°; find the volume at 35° F.—it is only necessary to reduce 35°F. to its equivalent on the Centigrade scale, and then to proceed as above. To heat 1 litre of air from 32°F. to 33°F. is the same as heating it from 0°C. to $(\frac{5}{9})$°C., and it therefore expands and occupies at 33°F. a volume of $1+\frac{5}{9}$ of ·00367 litre. Hence the coefficient of expansion of a gas for 1 degree Fahrenheit is 5-9ths of the coefficient for 1 degree Centigrade. It will be observed that the coefficient, $\frac{1}{273}$, expresses a certain fraction of the volume of the gas at 0°, and it is by this constant quantity that a gas expands when heated; and hence the coefficient of expansion at 10°—*i.e.* the fraction of the volume at 10° by which the gas will expand when heated to 11°—is less than the coefficient at 0°. The following table will make this clear:—

Temperature.	Number of cubic centimetres of gas.
0°	273
1°	(273) + 1
2°	(273 + 1) + 1
3°	(273 + 1 + 1) + 1
4°	(273 + 1 + 1 + 1) + 1

In each case, the gas expands for each degree by $\frac{1}{273}$rd of its bulk at 0°; but from 1° to 2° it expands by $\frac{1}{274}$th of its bulk at 1°—this being the same as $\frac{1}{273}$rd of its bulk at 0°; also between 3° and 4° it expands by $\frac{1}{276}$th of its bulk at 3°. Let A B (Fig. 23) represent

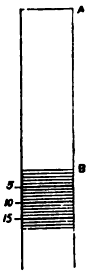

Fig. 23.

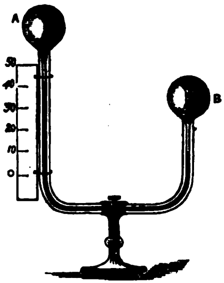

Fig. 24.

273 cubic centimetres at 0°C., then each of the divisions below A B represents 1 cubic centimetre; the rate of expansion is perfectly uniform at all temperatures, being always $\frac{1}{273}$rd of the volume at 0°, for each degree Centigrade.

Fig. 24 represents Leslie's* Differential Thermoscope. It consists of a bent glass tube, terminated at both extremities by bulbs. The bulbs and the adjacent parts of the tube contain air, but the rest of the tube is filled with a coloured liquid. If A is heated to the smallest extent above the temperature of B, the air in A expands and forces down the column of liquid; if it is cooled, however, below the temperature of B, the

* Sir John Leslie (1766—1832).

column of liquid rises towards it. This instrument is extremely delicate, but it does not indicate absolute temperatures; it shows merely if there is any difference between the temperatures of the two bulbs.

Regnault's Air Thermometer consists of a glass or porcelain cylinder, drawn out, as in Fig. 25, to a very fine point; it is generally used as a pyrometer, but frequently also in the place of the common mercurial thermometer, the indications of which are not absolutely correct, especially above the boiling point of water. In order to ascertain the temperature of a fire by means of this instrument, it is placed in the fire and is allowed to remain there as long as any air is driven out at the fine point; directly the current of air has entirely ceased, the point is hermetically sealed by a blow-pipe, and the instrument is then removed and allowed to cool. When cold, the point is carefully broken off under mercury; the mercury is forced into the cylinder by the pressure of the external air, and occupies the space of the air that has been expelled by the heat of the fire. The cylinder is surrounded with ice, so that whatever air remains is at 0°. When the mercury has ceased to rise in the cylinder, the latter is carefully removed, and the whole of the mercury contained within it is emptied into a graduated vessel, so that we can find its bulk. The cylinder is then *completely* filled with mercury, and the bulk of this mercury, *i.e.* the total capacity of the cylinder, is ascertained *as before*. *Suppose* that 1·2 litre of mercury enters the

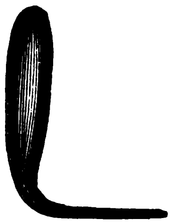

Fig. 25.

cylinder after cooling, and that the total capacity of the cylinder is 2 litres; the bulk of the air in the cylinder at 0° (after removal from the fire) is (2 —1·2) or ·8 litre, and the bulk of this air at the temperature of the fire is 2 litres; required the temperature of the fire.

·8 litre at 0° expanding to 2 litres is the same as
1 - - - $\frac{2}{\cdot 8}$ or 2·4 litres
i.e. 1 - expands by 1·4 litre
Now 1 - expands ·00367 litre for each degree
and therefore $\frac{1\cdot 4}{\cdot 00367} \times \cdot 00367$ litre for $\frac{1\cdot 4}{\cdot 00367}$ degrees
i.e. 1·4 litre for 381·5° nearly.

Hence the temperature of the fire is 381·5°.

But so many corrections have to be made, *e.g.* corrections for any alterations that may occur in the atmospheric pressure, and for the expansion undergone by the cylinder itself—that the air-thermometer has never come into general use. In determining the coefficients of expansion of gases, even between 0° and 100°, we have similarly to make these corrections, for the atmospheric pressure frequently varies, and the containing vessel is more capacious at 100° than it is at 0°. (See p. 80.)

Hot gas is relatively lighter than cold gas; hence, when a gas is heated, currents of gaseous particles are produced; gases, like liquids, become heated throughout their entire bulk principally by convection. This is one reason why porous clothes are warmer than those that are dense; the heat of the body would have to pass along the fibres which are themselves bad conductors of heat; the heat finds its way from fibre to fibre with great difficulty because the intervening gas which *occupies the* pores has a very low power of con-*ducting heat,* and it is more or less prevented from

conveying the heat by the comparatively close texture of the material. In the same way porous bricks tend to keep a house warm in winter and cool in summer. Grove found that, if he passed a current of electricity through a wire which successively traversed two globes, one containing hydrogen and the other carbonic acid, the portion of the wire that was surrounded with carbonic acid could be easily raised to a red heat while the other portion could not. The conclusion drawn from this experiment was that hydrogen *conducted* away the heat caused by the electric current much more readily than carbonic acid could do; but, as hydrogen is 22 times lighter than an equal volume of carbonic acid, its particles move more rapidly, it *conveys* heat better; and, in general, the heavier the particles of a gas are, the longer it takes to become heated.

Hot gas is always found at the top of a room and cold gas at the bottom; ventilators allow the hot air to pass out, and this is replaced by cold air that enters from below. A fire in a room creates a draught, because the hot gases pass up the chimney and are replaced by colder air from the room. If a fire is to be lighted in a room, the room itself should always be connected directly with the external air by some convenient contrivance; for, if this is not the case, the fire is supplied with air that comes from other parts of the house, and this air itself is replaced by the external air that finds its way down the chimneys of unlighted fires. The currents of air thus produced are represented in Figure 26; the fire is lighted at A. The following experiment proves that no air can pass down the chimney, A B, but *must come down* the other, C D. The bottle A B (Fig. 27), *is provided* with a cork, through which pass two

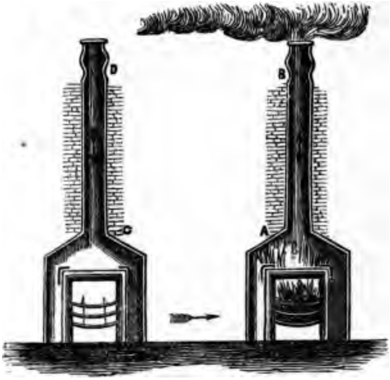

Fig. 26.

Fig. 27.

tubes. In one of these (A) a lighted candle (C) is fixed. A current of hot air passes up D, from the candle, as is shown by holding a lighted lucifer to it, when the flame of the lucifer is blown upwards; but, when presented to the tube A, the flame passes downwards, and the bottle becomes filled with the smoke of the extinguished lucifer. If the upper end of A is closed by pressing the finger upon it, the flame of the candle becomes dim; and it will ultimately be extinguished, though the tube D is open, unless the finger is quickly removed. If a lighted candle is placed at the bottom of a wide-necked flask (Fig. 28) it will gradually become dim, as the oxygen of the air is burnt and cannot be replaced down the single chimney; but, if the neck of the flask is divided by means of a cardboard partition,

Fig. 28.

A, two currents, an upward and a downward one, are immediately established, and the flame again becomes bright. Now it is easy to see that, if a gentle breeze is blowing in the direction B C, a considerable quantity of the obnoxious gases which pass up from the candle will be impelled again into the flask by the downward current. This is what actually occurs in houses that are badly ventilated; the fires are fed by air which comes down the chimneys of adjacent rooms where there are no fires, and consequently a fire in one room of a house will frequently cause another room to be filled with smoke; for the obnoxious gases that pass upwards from the fire are often blown towards the chimney which is conveying the downward current into the house.

Examples on the Air Thermometer.

1. It is found that, when an air-thermometer is removed from ice and placed in a furnace, 3-4ths of the original bulk of the air are expelled. Find the temperature of the furnace?—*Ans.* 817·4°.

2. The capacity of an air-thermometer is 3 litres; and, after removal from a furnace and immersion in ice, &c., as described above, the instrument is found to contain 1·8 litre of mercury. Find the temperature of the furnace?—*Ans.* 408·7°.

3. In the preceding question, if 1·8 litre of mercury had passed into the thermometer when the enclosed air was at 10°, what would have been the temperature of the furnace?—*Ans.* 433·7°.

4. A bulk of carbonic acid is required such that, when heated from 100° to 105°, it shall expand in all by 3·5 cubic centimetres; what bulk is necessary for this purpose?—*Ans.* ·2607 litre at 100°.

5. Find the coefficients of expansion of air, hydrogen, and carbonic oxide (at 0°) on the Réaumur scale? —*Ans.* ·00459; ·004576; 004586.

The above-mentioned currents are found, not only in small bulks of air, but also on a grand scale in the whole body of the atmosphere. The atmosphere consists of a mixture of different gases that completely envelop the earth. The actual height of the atmosphere above the earth's surface is different at different places; as it bulges out at the equator more than at the poles, its polar diameter is much smaller than its equatorial diameter. This bulging out at the equator is due to the rotation of the earth on its axis. The average height of the upper level of the atmosphere is from 70 to 80 kilometres above the level of the sea, or about 1-145th of the earth's diameter. The pressure of the atmosphere becomes less and less as we ascend in it; at the surface of the earth we have the weight of the whole atmosphere, but as we rise in the air we have the weight of a continually diminishing portion of it. The temperature of the atmosphere is exceedingly variable; speaking generally, it is much colder at the poles than at the equator, and the temperature falls as we ascend above the sea level. If we go on ascending, we at last arrive at a point where the average temperature is 0°, and above this point the average temperature is lower and lower. At the equator we have to rise more than 4½ kilometres before we reach this point,

and we there find perpetual snow all the year round; but as we approach the poles, we need not ascend so high in order to find this *level of perpetual snow*; and at last, when we come to the poles, we find that this level is at the level of the sea. The heat of the sun is only partially absorbed by the atmosphere; the rest reaches the earth and is then absorbed by the earth. The lower strata of air become heated, partly by actual contact with the earth, but chiefly by absorbing the heat which is given out by the earth, for (as we shall show further on) air is capable of absorbing the heat given out by the earth, but not that which comes direct from the sun. It follows from this that the air in the neighbourhood of the equator becomes strongly heated, and therefore an upward current is produced; the space thus vacated by the hot air is immediately occupied by air which flows from the cold polar regions, and this polar air is replaced by the air that had formerly ascended from the equator. Thus two sets of currents are produced, the upper and the lower *trade winds*. These currents occur in both the northern and the southern hemisphere, but we will consider the former only. In the northern hemisphere, then, the lower current ought apparently to come direct from the north, and the upper current direct from the south; but it must be remembered that the earth moves on its axis from west to east, and this axial movement is much more rapid at the equator than at the north pole. Hence the air coming from the north pole starts with a given velocity southward and eastward, but, as it approaches the equator, it is, as it were, *left behind by* the earth which has a very much greater

eastward velocity: and hence the current appears to blow from the north-east, while we ourselves seem stationary; just as, when we are in a ship, objects seem to move in a direction opposite to that in which we are going. But the upper current starts with a great eastward velocity, and as it approaches the poles, it passes over regions which have a much smaller eastward velocity; it therefore gains upon them, and leaves them behind, and appears to come from the south-west. The upper currents are very high above the sea level at the equator, and are said to be above the summits of the highest mountains in those regions, but their existence has been proved by the fact that the ashes and débris shot up from volcanoes have been conveyed by these currents to very great distances in the direction above indicated; moreover, the upper trade winds reach the sea level south of the north pole (or north of the south pole), a fact that accounts for the south-west wind so prevalent in the British Isles.

The *land breeze* and the *sea breeze* are other examples of natural aërial currents; these are caused by the land being hotter in the day-time than the sea, but colder in the night-time. Earth becomes more easily heated and more easily cooled than water. These breezes are more regular in the tropical regions than in the northern climates; and, by coalescing with the trade winds, they give rise to the *monsoons* of the Indian Ocean: north of this ocean is Asia, which becomes, during the summer months, more strongly heated than the water; but, during the winter, it is at a lower temperature.

The relative weights of all gases diminish with rise

of temperature; there is no gas known that contracts when heated. The following table gives the weight of 11·2 litres of several gases :—

11·2 litres of	Hydrogen meased. off at 0° ·76m. B.P. weigh			1	grm.
„	Marsh gas	...	...	... 8	„
„	Ammonia	...	...	... 8·5	„
„	Cyanogen	...	...	... 13	„
„	Carbonic oxide	...	...	... 14	„
„	Nitrogen	...	...	... 14	„
„	Air ...	...	...	... 14·45	„
„	Oxygen ...	...	...	... 16	„
„	Carbonic acid	...	...	... 22	„
„	Nitrous oxide	...	...	... 22	„
„	Sulphurous acid	...	...	... 32	„
„	Chlorine	...	...	... 35·5	„

Hence, if hydrogen is taken as the standard of comparison, the relative weight of marsh gas is 8, which means that any bulk of marsh gas, at 0°·76m. barometric pressure, weighs eight times as much as the same bulk of hydrogen at the same temperature and pressure. Since we have already agreed not to take atmospheric pressure into consideration, we will suppose the barometric column always to be at the same height, viz. 760 millimetres. But it must be remembered that the relative weight of a gas increases when the pressure upon it is increased, because, under these circumstances, the volume of the gas diminishes.

Now it is evident that, since *for all practical purposes* the expansibilities of the above-named gases are equal, *i.e.* one gas expands as much as another, their relative weights at different temperatures, as compared *with hydrogen at those temperatures*, are also the same

as their relative weights at 0°, as compared with hydrogen at 0°. This is clearly shown by the first of the following examples.

Examples on Relative Weights of Gases.

1. How much heavier are 2 litres of carbonic oxide at 20° than the same bulk of hydrogen at 20°?

$\because$ (1 + ·0732) litre of carbonic oxide at 20° becomes 1 litre at 0°.

$\therefore$ 1 " " $\frac{1}{1\cdot0732}$ "

$\therefore$ 2 " " $\frac{2}{1\cdot0732}$ "

$= 1\cdot86$ "

and $\because$ 11·2 litres of carb. oxide at 0° weigh 14 grammes

$\therefore$ 1·86 " " $\frac{14}{11.2} \times 1\cdot86$ "

i.e. 2·3 grammes nearly.

Hence 2 litres of carbonic oxide at 20° weigh 2·3 grammes nearly. Now 2 litres of hydrogen at 20° likewise contract to 1·86 litre when cooled to 0°, and as 11·2 litres at 0° weigh 1 gramme, it follows that 1·86 litre weigh $\frac{1}{11\cdot2} \times 1\cdot86$ gramme, or ·166 gramme nearly; and therefore 2 litres of hydrogen at 20° weigh ·166 gramme. The carbonic oxide at 20° is fourteen times heavier than the hydrogen at the same temperature, for $\cdot166 \times 14 = 2\cdot3$ nearly.

2. What is the relative weight of carbonic acid at 10°? *That is to* say, how much heavier than hydrogen

at 0° is carbonic acid at 10°? We have to find the weight of 11·2 litres of carbonic acid at 10°, and, as shown in the previous question, this is accomplished by finding the bulk at 0° of 11·2 litres of carbonic acid measured off at 10°. Its weight also can be found, for we know the weight of a certain bulk of carbonic acid at 0°, and from that can find the weight of any other bulk; this weight, then, is also that of 11·2 litres of carbonic acid at 10°, and the question now resolves itself into—how much greater is this weight than that of 11·2 litres of hydrogen at 0°? It must be remembered that the coefficient of expansion of carbonic acid is ·00371.—*Ans.* 21·213.

3. What is the relative weight of nitrous oxide at —20°? In this we must find the bulk at 0° of 11·2 litres of nitrous oxide measured off at —20°, remembering that its coefficient of expansion is ·003719.—*Ans.* 23·768.

4. At what temperature has carbonic acid the same relative weight as oxygen at 0°? That is, at what temperature do 11·2 litres of carbonic acid weigh 16 grammes? 11·2 litres of carbonic acid at 0° weigh 22 grammes, or (16 + 6)* grammes; therefore $\left(\frac{11{\cdot}2}{22} \times 16\right)$ litres of carbonic acid at 0° weigh 16 grammes; at what temperature does this volume expand to 11·2 litres?—*Ans.* 101·1°.

5. At what temperature has air the same relative weight as oxygen at 0°?—*Ans.* —26·4°.

* The gas has to expand by $\frac{6}{16}$ths or $\frac{3}{8}$ths of its volume at 0°. The required temperature is therefore ($\frac{3}{8}$ths of $\frac{1}{\cdot 00371}$)°.

6. What is the weight of 10 litres of air measured off at 150° ?—*Ans.* 8320·5 milligrammes.

7. 3 litres of carbonic oxide are mixed with 5 litres of carbonic acid, both at 15°; what is the weight of 2 litres of the mixed gases ?—*Ans.* 3·214 grammes.

8. How much heavier than air at 20° is carbonic acid at 30° ?—*Ans.* 1·07 times nearly.

9. What is the weight of a litre of ammonia at 200°, assuming ·00367 as its coefficient of expansion ?—*Ans.* 43·7 centigrammes.

10. What is the bulk of 10 grammes of cyanogen at 50° ?—*Ans.* 10·2855 litres.

If it were asked, what is the volume at —20° of 10 cubic centimetres of sulphurous acid measured off at 0° ? we should find, by employing the coefficient of expansion ·0039, that the required volume was 9·22 c. c. But, if we were to put our answer to the test of experiment by actually enclosing 10 c. c. of sulphurous acid at 0° in a thermometric tube, and cooling it down at the ordinary atmospheric pressure to —20°, we should discover that our answer was altogether wrong. The 10 c. c. would commence by contracting ·039 c. c. for each degree fall of temperature, but, as the temperature got lower, we should observe the gas contracting far more rapidly, and at last, at about —10°, it would *contract altogether*, and occupy *no* volume *as a gas*; it would then be a liquid. The great majority of gases liquefy when their temperatures are sufficiently low; all gases are merely the vapours of liquids, but these liquids boil at very low temperatures. Hence the difference between carbonic acid and steam is not a difference *of kind* but *only of degree.* The following table gives the tem-

peratures at which various substances boil, *i.e.* pass into the gaseous state :—

Nitrous oxide	—88°	Alcohol	78·4°
Carbonic acid	—78°	Water	100°
Ammonia	—34°	Hydric Acetate	120°
Sulphurous acid......	—12°	Mercury	350°
Ether	+35°	Sulphur	440°
Bromine	63°	Zinc	1040°

Liquid nitrogen, liquid oxygen, and a very few other liquids boil at such low temperatures that we have never been able to condense the gases—we have never been able to reach the temperatures at which these liquids boil.

There being no essential difference, then, between gases and vapours, we should expect that ether vapour or water vapour (steam), &c., would expand regularly for each degree Centigrade, and to the same, or practically the same extent as the gases already studied. For instance, 1 litre of hydrogen at 100° becomes very nearly 1·0026 litre at 101°. And we should expect that 1 litre of steam at 100° would also become 1·0026 litre if heated to 101°. But this is not the case; for steam at 100° and hydrogen at 100° are not under at all comparable circumstances. Hydrogen at 100° is far removed from the boiling point of its liquid, and is therefore a tolerably perfect gas; it has no tendency at all to liquefy; the separate particles of hydrogen have no inclination to run together: but the steam is close upon its point of liquefaction and its particles still cohere to a certain extent. We find that, when *heated, steam* expands far more rapidly than hydrogen,

until, at a certain temperature (about 120°), it begins to follow the laws of gases and to expand regularly for each degree rise of temperature to nearly the same extent as hydrogen and other perfect gases at that temperature.

$$1 \text{ litre of hydrogen at } 150^\circ \text{ becomes } \frac{1+151 \times \cdot 00366}{1+150 \times \cdot 00366} \text{ litre at } 151^\circ$$

also

$$1 \text{ litre of steam at } 150^\circ \text{ becomes } \frac{1+151 \times \cdot 00366^*}{1+150 \times \cdot 00366} \text{ litre} \quad ,,$$

It is therefore often stated that, *if* steam were a perfect gas at 0°, its coefficient of expansion would be ·00366 at that temperature; but the assertion is founded upon a useless and erroneous assumption.

All other vapours behave like steam in this respect, viz. that they become almost perfect gases when the temperature is sufficiently high above the boiling points of their liquids; and the higher the temperature is above the boiling point the more perfect is the gas. This fact will at once explain the anomalies before referred to, viz. carbonic and sulphurous acids, &c., which expand more rapidly than hydrogen and air. Carbonic acid is a liquefiable gas, and, at 100°, it is not so far removed from the boiling point of its liquid as is hydrogen at 100°; but, at higher temperatures, carbonic acid expands practically at the same rate as hydrogen.

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* The number would be rather higher than here indicated, as ·0039; compare this with the coefficient of expansion of sulphurous acid.

Hence the relative weight of steam, as compared with hydrogen *at the same temperature*, diminishes as the temperature rises from 100° to 150°, because steam between those temperatures is more expansible than hydrogen; but at higher temperatures, its relative weight, as compared with that of hydrogen *at the same temperature*, remains constant; or, in other words, its relative weight diminishes with rise of temperature in the same proportion as do the relative weights of other gases, because it expands to the same extent. We can deduce the rate of expansion of a vapour from its relative weights at different temperatures.

The relative weights of alcohol vapour at different temperatures, as compared with those of hydrogen at the same temperatures, are given in the following table:—

90°	... ...	24·84	approximately
100°	... ...	23·7456	,,
110°	... ...	23·184	,,
125°	... ...	23·0832	,,
150°	... ...	23·0976	,,
200°	... ...	23·0688	,,

From this table we see that alcohol vapour begins to be a perfect gas at about 125°, but that, below this temperature, it expands more rapidly than hydrogen. How are these numbers found?

EXAMPLE. Find the mean coefficient of expansion of alcohol vapour between 90° and 100°, from the above table.—*Ans.* ·0074889 nearly.

First, find the bulk of hydrogen that weighs 1 gramme at 90°, using for the sake of convenience the number ·00366 as the coefficient of expansion of hydrogen; the

same bulk of alcohol vapour at 90° weighs 24·84 grammes. Next, find the bulk of hydrogen that weighs 1 gramme at 100°; the same bulk of alcohol vapour at 100° weighs 23·7456 grammes. By a simple Rule of Three sum we can then determine the bulk of 24·84 grammes of alcohol vapour at 100°, and we already know its bulk at 90°; the difference between these two bulks is the total amount of expansion undergone by a certain bulk when heated 10 degrees. The answer is ·0074889 very nearly. The mean coefficient between 125° and 200° will be found to be very nearly ·00253, or the same as that of hydrogen between the same temperatures.

To determine the relative weight of any gas, we have to find out the absolute weight of any bulk of that gas, and also the absolute weight of the same bulk of the gas that we fix upon as the standard of comparison. In practice, it is usual to take air as the standard of comparison, because it is more easily obtained pure than other gases; but, for the purposes of calculation, &c., hydrogen is preferable to air. The determination of absolute weights must always necessarily precede the determination of relative weights; we must know the absolute weights in order to see the relation that subsists between those weights.

Gases are weighed in glass balloons. An empty balloon, *i.e.* one that has been exhausted by an air-pump, does not weigh so much as the same balloon filled with air; and a balloon full of air does not weigh so much as the same balloon full of chlorine. The balloons should be as large as possible and of as little *weight as possible*, for then the weight of gas contained

in them will not be an insignificant proportion of the whole weight. The gas to be weighed must be perfectly pure and dry, for impurities and moisture have weight; and the temperature, as well as the barometric pressure, must be accurately noted every time a gas is enclosed in a balloon, for these two conditions determine what would be the volume of the gas at 0° and 760 mm. Bar. Pr. Moreover, all the weighings must be done with the greatest care and accuracy, and it is here that we meet with the greatest obstacles.

All bodies weigh less in water than they do in air. Similarly a body weighs less in air than it does in vacuo. Properly speaking, 1 gramme is the weight of a cubic centimetre of water at 4°, *weighed in vacuo*. Air, like water, buoys bodies up, so that they lose in weight; and the loss of weight is the *weight of an equal bulk of air*. For instance, if the weight P (Fig. 29) balances the balloon B, which is full of some gas, P does not represent the weight of B; P is the true weight of the balloon, *minus* the weight of a bulk of air equal in volume to B. The quantity of air displaced by P is so small that we may disregard it altogether.

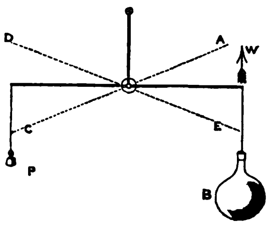

Fig. 29.

The force with which B is pressed upwards is represented by the weight of an equal bulk of air, W. Hence P and W together balance B. Now if the atmospheric pressure were to increase—the barometric column *rising*—B would receive a greater amount of support

from the atmosphere, and the arms of the balance would take up the position A C; P would more than balance the balloon; the latter would have a less apparent weight. If, on the other hand, the atmospheric pressure were to diminish, B would appear too heavy for P, and the arms would take up the position D E. This error, arising from the displacement of the air, was obviated by Regnault; he put a balloon on each arm of the balance so that the same volume of air was displaced on both sides, the balloons being as nearly as possible of the same capacity and of the same weight.

Glass, though visibly dry, is not really so at ordinary temperatures, but has a film of moisture on it. This film is drawn off by heat, but appears again as the glass cools. Precautions have to be taken that errors do not arise from this source. We cannot weigh the balloons when hot, for currents of air would be produced which would considerably interfere with the accuracy of the results; all substances, before being weighed, should be left for some time to assume the temperature of the surrounding air. The form of the apparatus used for weighing gases will show how necessary it is thought to protect the balloons from all disturbing causes.

Figure 30 represents Regnault's apparatus for determining the relative weights of gases. B is the counterpoising balloon, and we will suppose that it exactly balances A when the latter is quite empty, *i.e.* when it is exhausted by means of an air-pump. If A is now filled with the gas to be weighed, and is replaced on the balance, we shall have to put extra

weights into the scale-pan *b*, and these weights will be the weight of the gas. In order that the observation

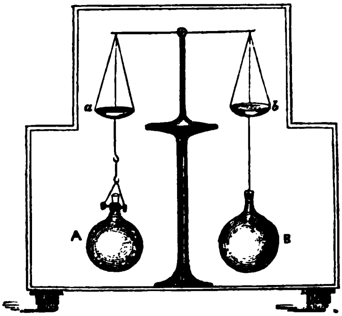

Fig. 30.

may be of any value, we must know the bulk of the gas (*i.e.* the volume of the balloon), and also the temperature and the pressure of the gas. The balloons have usually a bulk of about 1 decalitre. The table on page 84 contains the results of these observations.

There are several ways of determining the relative weights of those gases whose liquids boil at temperatures either neighbouring upon the ordinary temperature of the air or far above that temperature. The mode employed in each case must depend upon the nature of the substance; *e.g.*, if it boils at a comparatively low temperature, as ether or water, the gas can be contained in a glass vessel; but if it boils at a very high temperature, as with zinc, vessels of glass or porcelain must be used. The two principal methods, of which the others are *merely modifications*, are as follow :—


Fig. 31.

(1.) Dumas'* Method. A thin glass globe (Fig. 31), from ·1 to ·5 litre in capacity, has its neck bent and drawn out to a very fine point. After being thoroughly dried by repeatedly exhausting it and filling it with artificially dried air, it is carefully weighed while full of air, using all the precautions mentioned above. We will suppose that the weight of the globe, together with the contained air, is 10 grammes, and, for the sake of simplicity, that the temperature and the pressure of the air are 0° and ·76 metre of mercury to 0°. The liquid, the relative weight of whose vapour has to be determined, is now introduced into the globe; and the globe is then immersed in a hot bath, the temperature of which can be raised to about 50 degrees above the boiling point of the liquid. As the liquid passes into vapour, the air is driven out of the globe. When the temperature of the globe and of the vapour in it is about 50 degrees above the boiling point of the liquid, and when no more vapour is issuing from the fine open point of the globe, the temperature of the bath and the

* Jean Baptiste Dumas (b. 1800).

pressure of the atmosphere are noted, and the open point is immediately sealed by means of a blow-pipe. The globe is now withdrawn from the bath, washed and weighed with the greatest care; the weight—say 9·7 grammes—is the weight of the globe full of the vapour at the temperature of the bath—say 200°—and at the observed atmospheric pressure, which we will suppose to remain constant at ·76m. The next point is to ascertain the exact volume of the globe, so that we may know the bulk of air and the bulk of vapour contained in it; for we shall not consider here the amount of expansion undergone by the globe itself when heated, though in practice all such minutiæ have to be carefully allowed for. The bulk of the globe is found by breaking off the end of the neck of the globe under mercury; the mercury then enters and fills the whole globe (if all the air has been expelled) except the minute space occupied by the condensed vapour. If any bubbles of air remain, as is almost invariably the case, they have to be allowed for in the subsequent calculation. When the globe is full of mercury, the latter is emptied out into a graduated cylinder, and measured; this will give us the capacity of the globe; we will suppose it to be ·28 litre. Our data, then, are—

Capacity of the globe	·28 litre
Weight of globe and air at 0° ·76m. barometric pressure	10 grammes
Weight of globe and vapour at 200° ·76m. barometric pressure	9·7 "

10 grammes is the weight of the globe, together with ·28 litre of air at 0° ·76m. barometric pressure. *But*—

$\because$ 11·2 litres of air at 0° ·76 m. B. P. weigh 14·4 grammes

$\therefore$ 1 „ „ „ $\frac{14 \cdot 4}{11 \cdot 2}$ „

$\therefore$ ·28 „ „ „ $\frac{14 \cdot 4}{11 \cdot 2} \times \cdot 28$ „

$= \cdot 36$ „

Hence the weight of the globe by itself is (10 —·36), or 9·64 grammes.

But, since the weight of the globe by itself is 9·64 grammes, and the weight of the globe and vapour together is 9·7 grammes, it follows that the weight of the vapour is (9·7—9·64) or ·06 gramme. Hence ·28 litre of the vapour, at 200° 760 millimetres barometric pressure, weighs ·06 gramme. All that we now have left to do is to find the weight of the same bulk of hydrogen at the same temperature and pressure.

$\because$ $(1 + 200 \times \cdot 00366)$ litre of hyd. at 200° becomes 1 litre at 0°.

$\therefore$ 1 „ „ $\frac{1}{1 + 200 \times \cdot 00366}$ „

$= \frac{1}{1 \cdot 732}$ „

$\therefore$ ·28 „ „ $\frac{\cdot 28}{1 \cdot 732}$ „

= ·1617 litre at 0° nearly, or 161·7 cubic centimetres.

Now

$\because$ 11·2 litres of hydrogen at 0° weigh 1 gramme

$\therefore$ ·1671 „ „ „ $\frac{\cdot 1617}{11 \cdot 2}$ „

= ·01444 gramme nearly.

Hence ·28 litre of hydrogen, at 200° ·76 metre barometric pressure, weighs ·01444 gramme while the same

bulk of the vapour, at the same temperature and pressure, weighs ·06 gramme, *i.e.* very nearly four times as much as the hydrogen; hence, the relative weight of hydrogen being the standard of comparison, that of the vapour whose relative weight we have just found is 4, or more accurately $\frac{\cdot 06}{\cdot 01444} = 4{\cdot}155$. Dumas' method can be summed up in these words;—we find *the weight* of a certain known bulk of vapour at an ascertained temperature and pressure; and we compare it with the weight of a like volume of hydrogen at the same temperature and pressure.

(2.) Gay-Lussac's Method.—A small glass bulb, A, (Fig. 32) is weighed, and, after being completely filled with the liquid whose vapour has to be examined, it is hermetically sealed and weighed again. The difference between the two weights is the weight of the liquid, say ·08 gramme. It is then carefully passed up a graduated glass tube, C, that is filled with mercury and stands in a mercury bath, B. A large glass cylinder, D, open at both ends, is then lowered over the tube, so that one end shall be beneath the mercury in the bath; and water, oil, or some other transparent liquid is poured into it so as to envelop the tube completely. The bath is now *heated; the* mercury becomes hot and, by its agency,

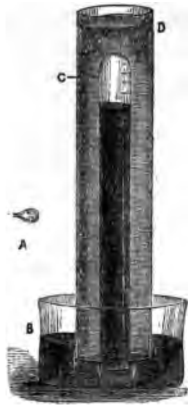

Fig. 32.

the water or the oil in the cylinder becomes hot also. The liquid in the glass bulb rises in temperature, expands, and, after bursting the bulb, gradually evaporates and forces down the mercury in the tube. The oil in the cylinder is well stirred so that the temperature may be uniform throughout; and, when all the liquid in the tube has passed into vapour, the temperature of the bath is urged to the point at which the determination is to be made. When this temperature is approximately arrived at, we have to observe the bulk of the vapour in the tube; this is done by noting the upper level of the mercury in the tube. We must also know the pressure to which the vapour is subjected; there is the atmospheric pressure acting upon it, and this pressure is ascertained by means of an ordinary barometer; but this is partially counterbalanced by the column of mercury in the tube containing the vapour. These observations give us the bulk of a certain known weight (·08 gramme in our example) of the vapour at an ascertained temperature and pressure. Disregarding the pressure, let us suppose that the vapour has driven the mercury down the tube so far that the mercury stands at precisely the same level inside and outside the tube; and let the bulk of ·08 gramme of the vapour at 150° be 24·2144 cubic centimetres.

Thus ·08 gramme of the vapour at 150° ·76 metre barometric pressure occupies 24·2144 cubic centimetres. We have now to find the weight of the same bulk of hydrogen at the same temperature and pressure in order that we may be able to say how much heavier the one is than the other. In the same way as before,

it is found that 24·2144 cubic centimetres of hydrogen, at 150° ·76 metre barometric pressure, weigh ·00139 gramme, and hence the relative weight of the vapour, as compared with hydrogen, is $\frac{\cdot 08}{\cdot 00139}$ or 57·554. Gay-Lussac's method is the reverse of Dumas'; we find the *bulk* of a known weight of the vapour—not the weight of a known bulk. The advantages, as well as the disadvantages, of this method are very great; we can make a great many observations at different temperatures with the same quantity of vapour and have not the trouble of weighing, &c., for each experiment. But the mercurial vapour that is formed in the tube gives rise to inaccuracies, especially at higher temperatures.

CHAPTER VI.

EVAPORATION.

Liquids, when exposed to the air, gradually disappear even at ordinary temperatures, but much more rapidly at high temperatures. This phenomenon is called *evaporation*, and the liquid is said to evaporate. But, when this evaporation goes on with such rapidity as to cause bubbles of the vapour of the liquid to pass speedily through the liquid, the liquid is said to boil or to be in a state of *ebullition*.

If a certain weight of water, say 1 kilogramme, is heated from 0° to 100°, it has at the latter temperature a certain quantity of heat in it; and, if the source of heat is removed, the water will gradually assume its original temperature. But, if the source of heat is not removed, the water at 100° will continue to receive as much heat as before (*i.e.* in the same time) and will boil away into steam. Now the temperature of the steam is the same as that of the water; and the temperature of the water never rises above 100°, though it is receiving the same quantity of heat as before when its temperature rose to 100°. Hence the change which the heat effects in water at 100° is not change of temperature, but change of physical condition, change of state, change of material form. The large quantity of

heat absorbed by water at 100°, in order to become steam at 100°, all goes towards producing this change in the physical condition of water. Conversely, if steam at 100° is condensed into water at 100°, it gives out the large quantity of heat that it formerly received. Absorption of heat occurs during the passage of a liquid into the gaseous state, and evolution of heat occurs during the passage of a gas into the liquid state. There is more heat in steam at 100° than is sensible to the touch or to the thermometer—but it is not in the steam *as heat*; it is there in another form. Steam, in this respect, stands to water in much the same relation as that in which coals stand to smoke and ashes; the coals may be at the same temperature as the smoke and ashes, but they are capable, by a simple process, of giving out a large quantity of heat. We distinguish between sensible or actual heat which is rendered evident by the thermometer, and those forces which have no action on the thermometer, but can easily be converted into sensible heat. We call the former actual, or *sensible heat*, and the latter *potential heat*. Potential heat is not heat, in the ordinary sense of the term; it is a form of expression used to indicate certain forces which can be converted into heat, and it is these forces which exist in steam and produce the large quantity of heat that is evolved when steam condenses. There is a great store of potential heat in coals and other combustibles.

When the presence of potential heat in steam was first discovered by Joseph Black (1728-99), of Glasgow and Edinburgh, about 1760, it was supposed that the heat was concealed in some inscrutable way in *the steam, as heat*, and it was called *latent heat*, a term

very generally employed in modern works. The latent or potential heat of a vapour is the heat that disappears as heat—or is converted into other forces—when the vapour is formed; it is the force or forces which become converted into actual heat when the vapour condenses into a liquid.

The following simple experiments will demonstrate the disappearance of heat during evaporation and the reappearance of heat during condensation. If a few drops of ether are poured upon one of the bulbs of a thermoscope, the liquid in the stem rapidly rises towards the wet bulb, showing that that bulb has been cooled below the temperature of the other bulb. The ether, as it evaporates, requires heat in order to become vapour and withdraws heat from the bulb. Alcohol, dropped upon the hand, produces a sensation of cold because, being readily volatile, it passes into the gaseous state rapidly and causes the transformation of a large quantity of heat into other forces; the heat required for this purpose is withdrawn from the hand, and the forces into which it is converted are resident in the alcohol vapour.

The "Anæsthetic Spray Producer" of Dr. Richardson, F.R.S., an instrument used in some surgical operations, is founded on this principle. "The apparatus (Fig. 33) consists simply of a graduated bottle for holding ether; through a perforated cork a double tube is inserted, one extremity of the inner part of which goes to the bottom of the bottle. Above the cork a little tube, connected with a hand-bellows, pierces the outer part of the double tube, and communicates by means of the outer part, by a small aperture, with the interior

of the bottle. The inner tube for delivering the ether runs upwards nearly to the extremity of the outer

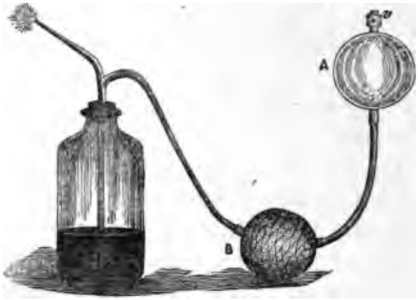

Fig. 33.

tube." The hand-bellows referred to consists of a flexible indiarubber tube that has two enlargements; one of these, A, is provided with a valve (*v*) opening inwards. When A is compressed, the air within it is forced along the tube into the graduated bottle; when the hand is removed from A, the latter, being elastic, resumes its former shape, and air rushes in through the valve (*v*) which then closes; A is compressed again, and this operation is repeated as rapidly as possible. B serves as a reservoir for the air and causes the current to be more continuous. "When the bellows are worked, a double current of air is produced, one current descending and pressing upon the ether, forcing it along the inner tube; and the other ascending through the outer tube and playing upon the column of ether as it escapes through the fine jet." * If this continuous

* *Med. Times and Gazette.* 1866, I. 116.

current of ether spray is passed upon the hand or any other part of the body, the temperature of that part is reduced to about —20°, and the feeling is destroyed as in the case of a frost-bite. During this "local anæsthesia," an operation can be performed on the part without causing the patient much pain.

Water evaporates slowly at ordinary temperatures; so slowly indeed, that there is not generally any sensible disappearance of heat. But, by special contrivances, we can prove that heat does disappear in all such cases. For instance, a thermometer, the bulb of which is surrounded with a wet rag, always marks a lower temperature than an ordinary thermometer. Some liquids, as mercury at —10° and hydric sulphate at 15°, do not evaporate at all at certain temperatures. Water evaporates even when solid; if the ground is covered with snow at the commencement of a long frost, the snow will be observed to disappear gradually, the ground beneath becoming visible. Water can be made to freeze by its own evaporation, one portion evaporating and removing heat from the rest. Wollaston's * Cryophorus consists of two glass bulbs connected together by a piece of glass tube as shown in Figure 34. The bulb A contains water, and is surrounded with wool or some

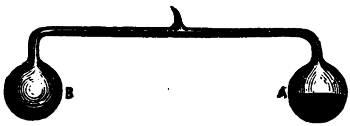

Fig. 34.

* William Hyde Wollaston (1766—1828).

other non-conducting material; the other bulb, B, is empty, and is placed in a freezing mixture. The space unoccupied by the liquid, being exhausted of its air, becomes rapidly filled with aqueous vapour which is immediately condensed in the cold bulb; more vapour is at once formed in the space and again condensed, and this process goes on until the remaining water freezes. The wool around A is to prevent the external air from supplying the heat which is required by the water before it can pass into the state of vapour. Another way of freezing water by its own evaporation is that proposed by Leslie. He succeeded in freezing water by placing it over hydric sulphate in the exhausted receiver of an air-pump, which was kept working the whole time; the receiver was no sooner filled with aqueous vapour than the latter was removed, partly by the action of the pump, and partly by being absorbed by the sulphate.

If steam at 100° is passed into water at 0°, the steam is condensed and the temperature of the water rises rapidly, and at last reaches 100°, at which point the steam no longer condenses, but passes unchanged through the water. If a gramme of water at 100° is mixed with another gramme of water at 0°, we obtain 2 grammes of water at 50° (very nearly); but, if a gramme of steam at 100° is mixed with, or passed into, a gramme of water at 0°, we obtain 1·19 gramme of water at 100°, *i.e.* nearly $1\frac{1}{5}$ gramme, while the rest of the steam, nearly $\frac{4}{5}$ gramme, remains uncondensed. Hence it is evident that steam at 100° contains a large quantity of potential heat—energy that can be converted into heat. Fig. 35 shows an arrangement for determining the quantity of potential energy in steam

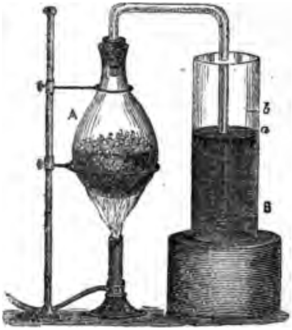

Fig. 35.

at 100°, over and above the quantity in water at 100°. The flask, A, contains pure water that is being boiled; the steam formed is caused to pass into a weighed quantity of water at 0° contained in a graduated glass vessel, B. If 5·37 kilogrammes of water at 0° are put into B, its temperature will be raised to 100° when 1 kilogramme of steam has been condensed; we shall then have 6·37 kilogrammes of water at 100°. The bulk of the water will be increased by about one-fifth, the level of the water rising from *a* to *b*; but a portion of this increase of bulk is due to the expansion of the water when heated from 0° to 100°.

From this experiment it is evident that 1 kilogramme of steam at 100°, if condensed into 1 kilogramme of water at 100°, gives out sufficient heat to raise the temperature of 5·37 kilogrammes of water from 0° to 100°, which is, as we shall afterwards show (p. 144), very much the same thing as raising the temperature of 5·37 kilogrammes of water from 0° to 1°. Now, the quantity of heat required to raise the temperature of 1 gramme of water from 0° to 1° is taken as the standard quantity of heat, and is called 1 *unit of heat.* Sometimes the quantity of heat required to raise the temperature of 1 kilogramme of water from 0° to 1° is

taken as the standard. In order to distinguish these two units of heat from each other, the former is called a gramme-unit, and the latter a kilogramme-unit of heat; but, as we shall always use the gramme-unit of heat, the distinguishing affix will be unnecessary. What is said of kilogrammes will apply equally well to grammes, as thus—1 gramme of steam at 100° in condensing to water at 100° evolves heat sufficient to raise the temperature of 5·37 grammes of water from 0° to 1°.

It follows, from what has been already explained, that, when one kilogramme of steam at 100° is condensed into water at 100°, a quantity of potential energy is converted into heat, and the heat thus produced amounts to 537000 units of heat. Two kilogrammes of steam will, in the same way, cause the evolution of twice 537000 units of heat. The only difference between water at 100° and steam at 100° is that the latter is the same as *the former plus a certain known quantity of potential heat.* When 537 units of heat are added to one gramme of water at 100°, the water becomes steam at the same temperature, and the 537 units of heat are converted into potential heat. This potential energy can be withdrawn from steam by certain contrivances, and it is then obtained in the form of sensible heat; 537 units of heat are thus produced by the condensation of a gramme of steam at 100° into water at 100°.

It will be shown further on (p. 114), that water can be made to boil at any temperature by altering the atmospheric pressure upon it, so that steam may, at any temperature, be converted into water at that

temperature. Now it has been found that, as the temperature of the steam diminishes, the heat given out by the condensation of the steam is greater in quantity; but, as the temperature rises, the heat given out diminishes in quantity. This is shown in the following table:—

Potential Heat of Steam.

Temperature.	Potential Heat.	Temperature + Potential Heat.
0°	606·5	606·5
50°	571·6	621·6
100°	537	637
200°	464	664

It was formerly thought that the sum of the temperature and of the potential heat gave, in all cases, the number 637; but this has been proved not to be so, as the third column in the above table clearly shows. A convenient formula has been devised by the aid of which we can find approximately the potential heat of steam at any temperature; this formula tells us that the sum of the potential heat and of the temperature of steam is equal in all cases to—

$$606{\cdot}5 + ({\cdot}305 \times \text{the temperature}).$$

Hence the potential heat of steam at any temperature is equal to—

$$606{\cdot}5 + ({\cdot}305 \times \text{temperature}) - \text{the temperature}.$$

Thus the potential heat of steam at 200°, *i.e.* the quantity of heat given out when steam at 200° becomes water at 200°, is—

$$\begin{aligned} 606{\cdot}5 + ({\cdot}305 \times 200) - 200 &= 606{\cdot}5 + 61 - 200 \\ &= 467{\cdot}5 \text{ units of heat,} \end{aligned}$$

a number not very far removed from the true one, 464.

The following table gives the potential heat of other vapours at the boiling points of their liquids when under the ordinary atmospheric pressure:—

Ether	... boils at	35°	... potential heat		90
Bromine	,,	60°	...	,,	45·6
Alcohol	,,	78°	...	,,	209
Turpentine	,,	159°	...	,,	69

Examples on Potential Heat.

1. What weight of ether-vapour at 35° must be passed into 3 kilogrammes of water at 0° in order to raise the temperature of the latter to 35°?

In order to raise the temperature of 3 kilogrammes of water 35 degrees, we must add three times 35000 or 105000 units of heat to it. Now, since 1 gramme of ether-vapour at 35° in condensing gives out 90 units of heat, it follows that 105000 units of heat are evolved by the condensation of $\frac{105000}{90}$ grammes of the ether-vapour, *i.e.* 1·1667 kilogramme.

2. Alcohol-vapour at 78° is passed through a spiral tube surrounded with 10 grammes of water, the initial temperature of which is 0°. What weight of alcohol-vapour has passed through the tube when the temperature of the water reaches 78°, supposing that the alcohol runs out of the tube directly it is condensed into a liquid at 78°? The heating of the tube is to be disregarded. The water must have had 780 units of heat imparted to it, and 1 gramme of alcohol-vapour, in con-

densing to a liquid at 78°, evolves 209 units of heat; hence 3·732 grammes of alcohol-vapour at 78° have condensed into liquid alcohol at 78° when the 10 grammes of water at 0° have reached 78°.

3. A flask containing 100 grammes of alcohol at 78° is immersed in a beaker that contains 90 grammes of water at 100°. How much of the alcohol will evaporate at 78°, providing that all the heat lost by the water goes to the alcohol? The water cannot evidently become colder than 78° unless it gives out heat to other objects besides the alcohol; hence the 90 grammes of water cool from 100° to 78°, *i.e.* 22 degrees, and therefore give out 90×22, or 1980 units of heat. Again, since 1 gramme of liquid alcohol at 78° requires 209 units of heat in order to become vapour at 78°, it follows that 1980 units of heat will evaporate $\frac{1}{209} \times 1980$, or 9·47 grammes nearly.

4. What weight of water would be heated from 0° to 1° (1) by the simple condensation of 3 grammes of bromine-vapour, (2) by that of 70 kilogrammes of the vapour of turpentine, (3) by that of 8·5 grammes of alcohol-vapour, each at the boiling points of their respective liquids?—*Ans.* 136·8 grammes; 4830 kilogrammes; 1·1765 kilogramme.

5. What will be the temperature of 30 grammes of water taken at 10°, after passing into it 1 gramme of steam at 100°? The 1 gramme of steam in condensing evolves 537 units of heat, and these raise the 30 grammes of water from 10° to between 26° and 30°—the precise number must be found by the student. Suppose it is 28°. The 1 gramme of water at 100° must then be

regarded as cooling down to 28°, *i.e.* through 72 degrees, during which process 72 units of heat are given out, and this quantity of heat raises the temperature of the 31 grammes of water from 28°. The answer is 32·2° nearly. This example will indicate to the student the method generally employed for ascertaining the potential heat of vapours; but so many corrections have to be made that the method, if fully described, would not be well understood at this stage.

Gases are the vapours of liquids that boil at very low temperatures; hence, when a gas is passed through a tube surrounded with ice, it will no more be condensed into a liquid than will steam when passed through a tube the temperature of which is 150° or 200°. But most gases will condense when passed through very cold tubes. For example, if sulphurous acid is passed through a tube surrounded with pure ether which is being compelled to evaporate very rapidly by transmitting air through it, the gas will be liquefied. Ether boils at 35°, and, when it evaporates rapidly, the temperature is lowered to —30°. Liquid sulphurous acid boils at —10·5°, and, when compelled to evaporate very rapidly, the temperature is lowered to —50°. If ammonia gas is passed through a tube surrounded with liquefied sulphurous acid which is rapidly evaporating, it is condensed to a liquid, for ammonia boils at about —34°. (See p. 87.)

When water evaporates, the vapour formed exerts a certain pressure upon all objects in contact with it, and this pressure is called its *Tension*. Consequently, if the Torricellian vacuum of a barometer is connected with a reservoir of water, the mercury will not stand

so high in the barometric tube; the pressure of the atmosphere, in this case, is balanced by the pressure of the mercury and the tension of the aqueous vapour.

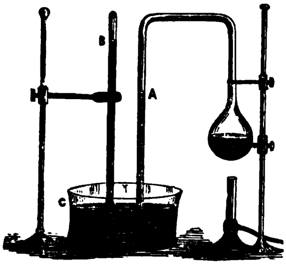

Fig. 36.

In Fig. 36, the atmospheric pressure, as represented by B C (760 millimetres of mercury at 0°), is equal to the pressure of the mercurial column A C together with the tension of the aqueous vapour above A. Hence the tension of the vapour is represented by a column of mercury of the height A B. If the space above A is made more capacious, the tension will still remain the same, since more vapour will be formed from the water in the reservoir. But, as the temperature of the water is raised, the tension of the vapour will increase; more vapour will be formed from the water in the reservoir, and this vapour will press the mercurial column down the tube. When the upper level, A, of the mercury inside the tube is at the same level as the mercury outside the tube, the tension of the aqueous vapour is equal to the pressure of the atmosphere. The temperature to which the water in the reservoir must be raised, in order that the tension of its vapour may be equal to the atmospheric pressure, is 100°—the temperature at which water boils. Ether-vapour exerts this tension at 35°, alcohol-vapour at 78°, hydric acetate at 120°, mercurial vapour at 350°, and so on (see p. 88). But, directly all the liquid in the reservoir has evaporated, and nothing but vapour

remains in the space above the mercury, the vapour begins to follow the laws of gases—its volume begins to increase by a certain fraction for each rise in temperature of one degree.

The following table gives the tension of aqueous vapour at various temperatures, the tension in each case being expressed in millimetres of mercury—(A B in the above diagram).

Tension of aqueous vapour.

—30°	·386	50°	91·982
—20°	·927	60°	148·79
—10°	2·093	70°	233·093
0°	4·6	80°	354·643
10°	9·165	90°	525·45
20°	17·39	100°	760
30°	31·548	150°	3581·23
40°	54·906	200°	11688·96

If the pressure of the atmosphere were reduced from 760 millimetres to 525·45 millimetres, water would boil at 90°. The temperature at which a liquid boils is that temperature at which its vapour has a tension equal to the pressure of the atmosphere; and the lower this atmospheric pressure is, the lower also are the temperatures at which liquids boil: ether boils with great rapidity even at the 0° when placed in the exhausted receiver of an air pump. A flask of water (Fig. 37) is boiled, and is then tightly fitted with a cork while steam is still issuing from it. If a cold wet rag is placed around the neck of the flask so as to condense the steam

Fig. 37.

in the space above the water, the liquid will immediately enter into ebullition, though its temperature is considerably below 100°. At the bottom of deep mines, water boils above 100°, but at top of high mountains it boils at so low a temperature as to be almost useless for culinary purposes. If articles of food are to be boiled at high elevations, the water used must be boiled under artificial pressure. Denis Papin (1647—1715) contrived an ingenious apparatus by means of which water can be boiled at any pressure greater than that of the atmosphere; this apparatus, called Papin's Digester, is much used in extracting gelatine from bones, an operation that requires the water in which the bones are digested to be at a very high temperature.

It has been found that an increase or a diminution of pressure of 2·7 millimetres of mercury raises or lowers the boiling point of water by ·1 or 1-10th of a degree. This is true, to a certain extent, for other liquids also; thus, ether boils at 35·1° when the pressure of the atmosphere is 762·7 millimetres. It was supposed by John Dalton (1766—1844) that, since the vapour of ether at 35° has the same tension as that of alcohol at 78°, and as that of water at 100°, the vapours of these liquids have the same tensions also at 25° (=35°—10°), 68° (=78°—10°), and 90° (=100°—10°) respectively. But this is found not to be the case except for very small intervals above and below the respective boiling points; and, with this reservation, we may say that an increase or a diminution of pressure of 2·7 millimetres of mercury raises or lowers the boiling point of any liquid by ·1 of a degree.

The pressure exerted by a gas is equal in magnitude *to the pressure* exerted on the gas. If we enclose a gas

in a tube, we can increase the pressure of the gas by increasing the pressure upon it, and we have already seen that the volume occupied by a gas diminishes as the pressure increases. But, if we go on increasing the pressure, we at last reach a limit; a gas will not exert more than a certain pressure. If we endeavour to compel it to exert a greater pressure, a portion of it becomes liquid, and the pressure of the remaining vapour is the same as before. This greatest pressure is called the *Maximum Tension* of the vapour, and a vapour exerts its maximum tension when any increase of pressure upon it will liquefy it. The table on p. 114 gives the maximum tensions of aqueous vapour at different temperatures. When the vapour is exerting its maximum tension, it is said to be *saturated.* Hence ordinary gases are unsaturated vapours, and we can convert them into saturated vapours by two processes; 1st, by diminishing their temperature; 2ndly, by increasing the pressure upon them. Thus, sulphurous acid is reduced, at the ordinary atmospheric pressure, to a saturated vapour at —12°, ammonia at —34°, carbonic acid at —78°, and so on (see p. 88). On the other hand, if ammonia is generated in a closed bent tube (Fig. 38), the pressure upon it is so great that

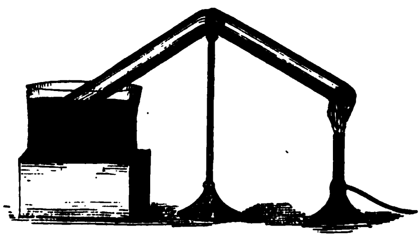

Fig. 38.

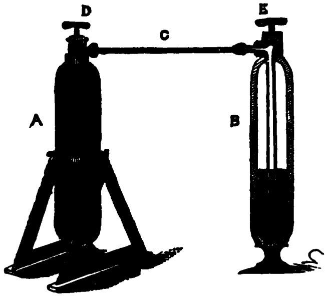

Fig. 39.

it is liquefied, as at A. (See *Barff's Chem.* p. 117.) Sulphurous acid becomes liquid if the pressure upon it is three times the ordinary pressure of the air. Carbonic acid is liquefied at a high pressure in an apparatus called Thilorier's Condenser (Fig. 39).

The first-mentioned process is made use of in distillation; the liquid required to be distilled is placed in a retort, the neck of which is connected with a cooling apparatus, *e.g.* a tube around which a current of cold water is continually running, as shown in Fig. 40. The

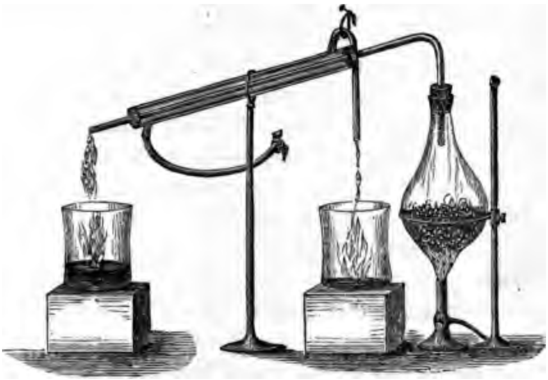

Fig. 40.

liquid, when heated, passes off gradually into vapour; *and the vapour,* as it enters the cold part of the neck,

condenses into a liquid and can be run off into a receiver. A process quite similar to this is always being carried on to a greater or less extent in nature. Water evaporates more readily when hot than when cold, and hence more aqueous vapour comes from the seas of the tropics than from those of the northern climates; this vapour, when it reaches a cold locality, condenses, and the potential energy in it becomes converted into actual heat; and thus, through the medium of aqueous vapour, there is a more equal distribution of temperature over the globe than if there were no such phenomena as those of potential heat.

The boiling point of a liquid is influenced to a remarkable extent by the nature of the vessel in which the liquid is boiled. It will be remembered that, when showing how the boiling point of water is found for the purpose of graduating a thermometer, a metallic vessel was said to be used; in a glass vessel, water boils a little above 100°, and it is noticed that the bubbles of steam come off from certain points of the vessel. Water will not readily pass into the gaseous state unless the vessel in which it is being heated has many small projections, and very often, when heated in a smooth vessel, it boils in a convulsive manner.

If a small quantity of water is thrown into a red-hot platinum crucible, it will not boil; it enters into what is called the *spheroidal state*, forming small spheroids or globules of water that float about the crucible, resting not on the crucible but on a layer of aqueous vapour. The temperature of the water in this condition never reaches 100°; but, when the temperature of the crucible falls, the water comes into contact with the hot surface, and passes off rapidly into vapour.

Questions on Evaporation.

1. If water at 40° is passed into the Torricellian vacuum of a barometer, by how much will the mercurial column be depressed? Does the amount of depression depend on the size of the vacuum, and why? What changes will take place if the tube is thrust down in the cup containing the mercury?

2. Explain why the table on page 114 gives the *maximum* tensions of aqueous vapour at different temperatures.

3. The pressure required to liquefy a gas is less when the temperature of the gas is low than when it is high. Explain the reason of this.

4. What becomes of the heat of the lamp when a liquid is distilled as described on page 117?

5. It has been said that a snowstorm "demonstrates just as rigidly the operation of heat as the action of cold."* Explain this statement.

6. Three barometers are taken; some alcohol is passed up the tube of one, some ether up that of another, and some water up that of the third. What will be the relative heights of the mercurial columns in the three tubes, supposing that an excess of liquid is used in each case? In this experiment the upper part of the barometric tube is at first colder than the lower part beneath the mercurial column; why is this so?

7. In what respects do gases differ from vapours?

8. Explain the effect of pressure upon the rate of

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* *Tyndall*, "Heat as a mode of Motion," p. 187.

expansion as exhibited in Regnault's experiments, page 67.

9. What would be the effect of increasing the pressure and the temperature of a gas at the same time?

10. What would be the effect of diminishing the pressure and the temperature of a gas at the same time?

11. Steam at 100° is a very imperfect gas. How could it be rendered more perfectly gaseous without altering the temperature?

12. In Wollaston's "Cryophorus," heat is withdrawn from the water to make it freeze. Explain precisely what becomes of this heat.

13. A fall of rain in cold weather frequently causes the temperature to rise considerably. Explain the reason of this.

Liquids evaporate not only in vacuous spaces (*e.g.* above the mercury in a barometric tube), but also into spaces already occupied by permanent gases, as, for instance, the atmosphere; but they evaporate more slowly—that is the essential difference; the quantity of vapour formed is almost exactly the same whether the space was previously occupied by another gas or not. A natural example of this is the familiar case of the evaporation of terrestrial waters. The vapour is formed slowly from such waters, but the rate of evaporation is increased if the wind is high (because the vapour is carried away as soon as formed) and also if the temperature is high. The atmosphere always contains a certain quantity of aqueous vapour, sometimes more, *sometimes less*; this vapour is condensed into minute

globules in the upper and colder regions of the atmosphere, and thus gives rise to clouds. After sunset the earth gives out more heat than it receives, and consequently becomes colder, and hence the lower strata of air in contact with it deposit moisture in the form of dew.

The moisture of the clouds reaches the earth in various ways. A portion of it falls as rain, hail, or snow, and, running down the sides of hills, occasions streams and rivers. In many cases the condensed vapour does not reach the sea-level at once, but remains on high mountain-tops in the form of great masses of snow, which, however, gradually melt, and produce mountain torrents. Sometimes, however, the snow thus formed becomes consolidated into glaciers (masses of ice), which gradually work their way down the sides of the mountains to the sea, and by degrees melt away in mid-ocean.

It is often necessary to estimate the amount of moisture that is present in the atmosphere at any given time. Instruments used for this purpose are called *hygrometers* (measures of moisture). The principle upon which most hygrometers are constructed is this: we determine at what temperature the vapour in the air has its maximum tension, *i.e.* at what temperature moisture just begins to separate from the air; this temperature is called the *dew-point*. When we know the dew-point, it is not difficult to calculate approximately the absolute quantity of moisture in any bulk of the air.

Daniell's Hygrometer (Fig. 41) consists of a closed *glass tube, terminating* at both extremities in bulbs,

Fig. 41.

and bent twice at right angles, as shown in the diagram. One bulb, A, is empty, and is surrounded with muslin. The other bulb, B, is artificially blackened so that any moisture upon it can be readily seen; this bulb contains some ether, and also a thermometer that is partly immersed in the ether. The whole rests upon a stand, C, which carries another thermometer that indicates the temperature of the air. If some ether is poured on the muslin around A, the temperature of the bulb falls, and the ether-vapour within it, derived from the liquid in B, will become liquid. The space thus rendered vacant will be instantly filled with more vapour from B. The evaporation going on in B will lower the temperature of B, and this process can be carried on until the bulb, B, is cold enough to cause dew to be deposited upon it from the surrounding air; the thermometer within B will then indicate the dew-point. If some ice is put into a perfectly dry tumbler,

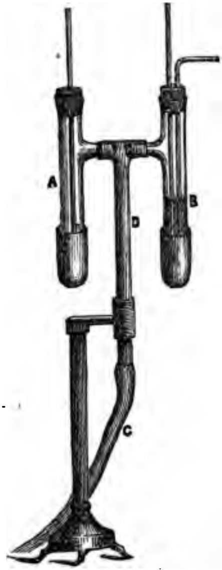

Fig. 42.

the outside of the tumbler soon becomes wet from the deposition of dew, just as B becomes wet.

Regnault's Hygrometer (Fig. 42) admits of much greater accuracy. It consists of two similar tubes, A and B, each fixed into a bright silver cup. A thermometer is fixed into the cork of each tube; but B is also provided with a long glass tube open at both ends, the lower end being beneath some ether that is in B. The upper part of B is connected, as shown in the figure, by means of indiarubber tubing, C, with an aspirator or vessel full of water. When water is allowed to run from this vessel, it draws air along the tube D through the ether; the temperature of the tube B is thus lowered, and the moisture that is deposited on the bright silver cup is readily visible. Hence the thermometer in B will indicate the dew-point, while that in A will indicate the temperature of the air.

CHAPTER VII.

LIQUEFACTION.

Nearly all solids can be liquefied, except, of course, those that decompose below their melting points, and nearly all liquids can be solidified. The lowest melting point at present known is —80°, the highest is about 2000°.

Speaking generally, a solid expands when it melts, that is, it occupies a larger volume in the liquid than in the solid state; just as a substance always occupies a much greater volume when gaseous than when liquid. But some solids contract when they become liquid, and the liquids thus formed will expand again when they are solidified. An example of this behaviour is afforded us by ice and water. Ice contracts when it melts, and water expands when it freezes. If a test tube, half filled with water, is placed in a freezing mixture, and is withdrawn after a few minutes, the test tube will be found to be broken. It is in this way that water-pipes are broken in frosty weather, though the fracture does not become evident until the ice begins to thaw or melt; for, so long as it is solid, it remains in the pipe as any other solid would do. Sometimes the pipes are *rather elastic,* and are therefore stretched by the water

in the act of freezing; but, as they do not contract again to their former bulk, a second frost will be more likely to make them burst. The force exerted by water in expanding is enormous; cast-iron bottles can be easily broken by filling them with water, then closing them and immersing them in a freezing mixture. If, during rainy weather, waters fills up a fissure in a rock, when the cold weather comes the water will freeze and burst the rock outwards. But the most general way in which rocks are broken up by freezing water is the following: drops of water get between the roughnesses on the surface of a rock, and, on freezing, disintegrate the surface, producing a small powder or dust. Tough clay soils are always ploughed before winter comes on, and are then left open to the weather; the water gets in amid the clay, and in frosty weather freezes and causes the clay to swell up. When a thaw comes, the formerly tough earth more or less completely falls into powder.

Since ice occupies a greater volume than the water from which it was formed, it follows that ice must be relatively lighter than water. It floats on the surface of the water, thereby retarding to a great extent any further process of solidification. 1 cubic centimetre of water at 0° if frozen, forms 1·102 cubic centimetre of ice at 0°; from this fact we can determine the relative weight of ice at 0° as compared with water at 4°.

1 c. c. of water at 4° weighs 1 gramme, and becomes 1·0001269 c. c. at 0°, (See page 60);

but

1 c. c. of water at 0° forms 1·102 c. c. of ice at 0°

$\therefore$ 1·0001269 c. c. of water at 0° forms $1{\cdot}102 \times 1{\cdot}0001269$

$= 1{\cdot}10214$ c. c. of ice at 0°.

$\therefore$ 1·10214 c. c. of ice at 0° weighs 1 gramme

$\therefore$ 1 c. c. „ „ $\frac{1}{1{\cdot}10214} = {\cdot}907$ grm.

Hence the relative weight of ice at 0° is ·907, as compared with water at 4°. The more accurate number is ·918. Increase of pressure prevents water from expanding, and the act of freezing causes water to expand; hence increase of pressure and the act of freezing, in the case of water, are antagonistic. Water subjected to great pressure does not freeze at 0°, because it cannot expand. At a pressure of about 8 atmospheres (8 times 760 millimetres of mercury) it freezes at —·059°; at a pressure of about 17 atmospheres, it freezes at —·129°; and ice at —18° has been melted by increasing the pressure to 13,000 atmospheres. On the contrary, those substances that contract on becoming solid, become solid at higher temperatures when under great pressure, because, in this case, increase of pressure assists in the process; thus sulphur at the ordinary pressure melts at 107°, but, under a pressure of 520 atmospheres, it melts at 135°.

Ice at 0°, if it is exposed to the flame of a lamp, will melt; but the most delicate thermometer immersed in the liquid will not indicate any rise of temperature so long as any ice remains in the mixture, though a large quantity of heat is being poured into it. The water, into which the ice is converted by the agency of heat, is also at 0°, and the actual heat of the flame has become converted into the potential heat of the water.

In water there are other forces at work than those that we find in ice, for the particles of water are more mobile and the force of cohesion is not so powerful. As we do not accurately know the precise nature of all the forces into which the heat is converted, we class them all together under the name of the *potential heat of water*—they are varieties of potential energy. Similarly, all solids, at their melting points, require a certain quantity of heat in order to become liquid without change of temperature, and the quantities of heat thus required are called the potential heats of the liquids.

When a liquid becomes solid, the potential energy within it is evolved in the form of heat; it is reconverted into actual heat; and a liquid will not become solid unless the potential energy within it is got rid of in some way. The quantity of heat absorbed (or converted into potential energy) during liquefaction is exactly equal in amount to the quantity of heat evolved during solidification. There is, consequently, a disappearance of heat during liquefaction, and an evolution of heat during solidification; and these phenomena are most apparent when a solid is compelled to become liquid without artificially applying heat to it, and when a liquid is compelled to become solid without exposing it to a low temperature. If crystallised ammonic nitrate is powdered and then mixed with an equal weight of water, the nitrate, being readily soluble in water, will be compelled to dissolve, and consequently to become liquid. For this purpose it requires heat which, not being freely supplied, is abstracted in large quantity from the water, the containing vessel, and other surrounding objects; water in a test tube, if immersed in

the mixture, will be frozen. The following are other examples of freezing mixtures :—

Water .... Ammonic nitrate Sodic carbonate	equal weights, reduces the temperature from	10° to —20° nearly.
Snow .... 2½ Sodic chloride 1	parts by weight „ „	„ 0° to —20°
Snow .... 1 Calcic chloride 2	„ „ „ „	„ 0° to —45°

It was mentioned in a previous chapter (see p. 59) that water can be cooled far below its freezing point without freezing, but the least agitation, or the introduction into it of a particle of ice, will cause it to become solid immediately. This solidification is accompanied with evolution of heat; if the water is far below 0°, say at —10°, when it is agitated, the process of solidification occasions the conversion of potential into actual heat, and the quantity of heat evolved is sufficient to raise the whole of the water to 0°. Water will dissolve a much larger quantity of sodic sulphate or of sodic hyposulphite when hot than when cold; and, if it is saturated with one of these salts when hot, and is then allowed to cool slowly out of contact with the air, the whole of the salt will often remain in solution at the ordinary temperature. This solution is said to be *supersaturated;* if it is agitated, or if one of the bulbs of a thermoscope is plunged into it, it will immediately become semi-solid and its temperature will rise considerably, as shown by the thermoscope.

If 10 grammes of water at 0° are mixed with 10 grammes of water at 100°, we obtain 20 grammes of water at 50°; but, if 10 grammes of ice at 0° are mixed with 10 grammes of water at 100°, we obtain 20

grammes of water at 10·5°. The quantity of heat absorbed or converted into potential energy during the process of liquefaction is evidently that quantity which is sufficient to raise the temperature of 20 grammes of water from 10·5° to 50°; *i.e.* 20 grammes of water through 39·5 degrees of temperature. But the quantity of heat which will raise the temperature of 20 grammes 39·5 degrees is equal to that which will raise the temperature of 20 times 39·5 or 790 grammes of water 1 degree, *i.e.* 790 units of heat. Hence 10 grammes of ice at 0°, in order to become water at 0°, require 790 units of heat; and therefore 1 gramme of ice requires 79 units of heat. We say that the potential heat of water is 79; by which we mean that 1 gramme or 1 kilogramme or any other weight of ice at 0°, in order to become water at 0°, requires an amount of heat that is sufficient to raise the temperature of 79 grammes, or 79 kilogrammes of water one Centigrade degree; or, that the quantity of heat developed by the inverse process of solidification is sufficient to raise the temperature of the above weight of water one degree.

A more convenient way of arriving at the number 79 from the experimental fact above given is the following. Any substance at any known temperature, say —50°, has a certain quantity of heat in it. Water at 100° has a certain quantity, though we do not know how much; but we do know how much *more* heat there is in 10 grammes of water at 100° than there is in any weight of water at 10·5°; and, in finding out how much more heat there is, it is convenient to regard only the quantities of heat due to a change of temperature from 0° to 100°, and from 0° to 10·5°, thus:—

10 grammes of water at 100° contain 1000 units of heat more than 1 gramme at 0°.

20 grammes of water at 10·5° contain 210 units of heat more than 1 gramme at 0°.

∴ (1000—210) or 790 units of heat have apparently disappeared: since these have been absorbed by 10 grammes of ice at 0°, each gramme of ice must have absorbed 79 units of heat. In the above calculation, it must not be said that 10 grammes of water at 100° contain 1000 units of heat, for they contain much more heat than that: they contain 1000 units of heat + all the heat in 1 gramme of water at 0°, and this latter quantity is unknown.

When we say that the potential heat of liquefaction or fusion of sulphur is 9·4, we mean that 1 gramme of sulphur at its point of solidification (115°), in order to pass into the solid state without change of temperature, must evolve as much heat as would raise the temperature of 9·4 grammes of water from 0° to 1°. The following table gives the potential heats of fusion of a few liquids:—

Water	at	0°	79
Sulphur	,,	115°	9·4
Phosphorus	,,	44°	5
Mercury	,,	—40°	2·82

The high potential heat of water partly accounts for the fact that it takes so long for natural waters to freeze; but when once frozen, the ice takes a longer time to melt than any other solid *under similar conditions.* No liquid, at the temperature at which it becomes solid, contains within it so much potential energy as water does at 0°. During a long and bitter winter, all natural waters

are continually giving up their potential energy in the form of heat; thus, to a very great extent, moderating the excessive cold. Some of these waters give up at last all that potential energy to which they owe their liquid state, and become frozen. This ice, during the summer, absorbs a large quantity of the heat emanating from the sun, and stores it up within itself as *potential energy* which is reconverted into sensible heat during winter. But there is another circumstance that has a great effect upon the temperature of natural waters, and it is to this to which we must now pay special attention.

Questions on Liquefaction.

1. Water expands when cooled from 4 to 0°. Why does not this cause water-pipes to burst in winter in the same way as the freezing of water does?

2. A glass tube, sealed at both ends and almost full of water, is surrounded with ice; after a time, the tube is found to be broken, but the water within it is not frozen. Explain this.

3. Taking the relative weight of ice at 0° as ·918, deduce the amount of expansion undergone by water on freezing.

4. What becomes of the potential energy of water when it is frozen by being immersed in a freezing mixture?

5. How much water at 100° must be added to 1·35 kilogramme of ice at 0° in order that the mixture, after total fusion of the ice, may be 0°, 10°, and 20°?

—*Ans.* 1066·5 grammes; 1335 grammes; 1670·625 grammes.

6. In the previous question, what weight of steam at 100° must be used in each case?—*Ans.* 167·425 grammes; 191·627 grammes; 216·613 grammes.

7. What weight of water at 100° is required to melt 3·5 cubic centimetres of ice at 0° (relative weight ·918)? —*Ans.* 2·537 grammes.

8. What weight of steam at 100° must be passed into 1·2 litre of ice at 0° in order that the mixture may be at 50°?—*Ans.* 242·09 grammes.

9. What weight of water at 100° is required just to melt 8·55 grammes of phosphorus at 44°?—*Ans.* 763·4 milligrammes.

10. If 25 kilogrammes of water at 95 are mixed with 55·5 grammes of ice at 0°, what will be the temperature of the mixture after total fusion of the ice?—*Ans.* 94·6°.

CHAPTER VIII.

SOME EFFECTS OF HEAT.

We have already had examples of some of the most important effects of heat on matter. There is, in fact, no property of matter, except weight, that is not to a greater or less extent influenced by heat. We have seen that heat will produce a change in the physical state of a substance; it will cause a solid to pass into the liquid state, and a liquid to pass into the gaseous state. And these changes we have just studied, both qualitatively and quantitatively; we have studied not only what sort of change takes place, but also what quantity of heat is required to produce a certain quantity of change. But, of all the effects of heat, the most evident is change of temperature. When heat is applied to a substance, it almost invariably causes the substance to become hotter; the principal exceptions to this statement are solids at their melting points and liquids at their boiling points.

We have now, therefore, to answer the question—What quantity of heat is required to raise the temperature of any particular substance, say from 0° to 1°, or from 180° to 181°, and so on? But the following considerations will show that this question cannot at present be answered by direct experiment; and, if answered at

all, the answer must, with our present store of knowledge, be wholly theoretical. When a substance, say sulphur, is heated from 0° to 1°, a certain amount of heat is used up; this heat produces a certain quantity of change in the sulphur, and is got back again when the sulphur cools down to its former temperature, 0°. Now this quantity of heat can be easily determined, as will be afterwards shown; if the weight of the sulphur thus heated was 5 grammes, the quantity of heat used up, when its temperature rises from 0° to 1°, is found to be about 1 unit of heat. But change of temperature is not the only change produced in the sulphur when it is heated from 0° to 1°: the sulphur also undergoes change of bulk or volume—its particles separate from one another; and this change is effected by the heat. Change of bulk and change of temperature are simultaneous, and the 1 unit of heat produces both these changes in the 5 grammes of sulphur. There are likewise other changes produced in matter simultaneously with those just mentioned. A crystal sometimes changes its crystalline form when heated, *e.g.* octohedral sulphur, when heated between 100° and 110°, is converted into prismatic sulphur. Phosphorus exhibits other remarkable changes, and pyroelectric crystals still others. Again, rise of temperature is not always accompanied with increase of volume, as in the cases of Rose's fusible metal, water below 4°, &c.

When, therefore, we say that 1 gramme of sulphur, in rising from 0° to 1°, requires 1-5th of a unit of heat, we understand that a certain unknown proportion of this 1-5th of a unit is employed in effecting change of volume, as well as other changes more or less unknown:

that a certain quantity, in other words, is converted into potential energy of some kind. When ice at 0° is acted upon by heat, all the heat is converted into potential energy; the same occurs with water at 100°, or with alcohol at 78°. When water at 0° or ether at 10° is acted upon by heat, only a portion of the heat becomes potential; the rest remains sensible, raising the temperature of the body.

Not being acquainted with the precise nature of all the changes that bodies undergo when heated, we must be content with the knowledge of the quantity of heat required to produce a certain change of temperature together with the other simultaneous changes of bulk, crystalline form, &c.; and in the following chapter we shall study this subject; omitting, however, the quantity of heat required to produce change of physical state, since this has already been considered.

In anticipation it may be stated that we should be led *à priori* to the conviction that equal bulks of any two solids, as platinum and tin, or of any two liquids, as mercury and water, would require different quantities of heat to raise them one degree in temperature; because the rate of expansion, and probably therefore some of the other changes (as, for instance, the force of cohesion), are greater in the one than in the other. The amount of potential energy in gases is so great, that in the majority of cases we lose sight of any attractive force between the gaseous particles. The particles of a gas, like all other particles of matter, attract one another; but there is also a force of repulsion amongst the particles, and this force is antagonistic

to and (in the case of perfect gases) greater than that of attraction. Hence probably the only change, besides that of temperature, which a gas undergoes, when heated, is change of bulk; and, since this change is practically the same whatever gas we experiment upon, we might well expect that the same quantity of heat would be required to raise, from 0° to 1°, the temperatures of equal volumes of air, hydrogen, nitrogen and other permanent gases. The only work that the heat has to do in each case is to raise the temperature of the gas, and to increase its volume, *i.e.* to overcome the pressure of the atmosphere, this pressure being practically the only force preventing gaseous expansion.

How far these theoretical considerations are in accordance with fact will be seen in the next chapter; but it is on account of them that we treat the subject under two heads :—(1) Solids and Liquids, (2) Gases, including Vapours.

Question.

Why should we suppose that equal *volumes* of different gases require the same quantity of heat to raise them one degree in temperature, and not equal *weights?*

CHAPTER IX.

RELATIVE HEAT.

I.—OF SOLIDS AND LIQUIDS.

If 1 gramme of water at 100° is mixed with 1 gramme of water at 0°, the result is 2 grammes of water at 50°. But, if the gramme of water at 100° is mixed with a gramme of mercury at 0° and the two liquids are well shaken up together so as to be as nearly as possible of the same temperature, we find that the temperature of the water or of the mercury is between 96° and 97°. We have to remember that the containing vessel also is heated, and that the surrounding air carries away a certain quantity of heat. Hence, in a rough experiment, the temperature actually found is much below 96°; but, if we allow for the heating of the vessel and of the air, the temperature of the liquids after agitation —none of the heat being lost—is 96·8° very nearly. The water has lost 3·2 units of heat, and this quantity of heat was sufficient to raise the temperature of a gramme of mercury 96·8 degrees.

$\therefore$ 3·2 units of heat raise 1 gramme of mercury 96·8 degrees.

$\therefore \dfrac{3{\cdot}2}{96{\cdot}8}$ " " " " 1 degree.

i.e. the quantity of heat requisite to raise the tempera-

ture of a *gramme* of mercury one degree is equal to that which will raise $\frac{3{\cdot}2}{96{\cdot}8}$ or ·033 gramme of water one degree (or ·033 unit of heat). The number ·033 is called the *relative*, or, more commonly, the *specific heat* of mercury; ·033 represents the *relative* quantity of heat required by mercury as compared with that required by an equal weight of water. The relative heat of water is taken as unity in the same way as its relative weight is.

If 1 gramme of iron at 100° is thrown into 1 gramme of water at 0° and is well shaken, the temperature of the whole is about 10·22°, allowing, as before, for the necessary errors. The water has acquired 10·22 heat-units, and this quantity of heat was evolved when the temperature of 1 gramme of iron fell from 100° to 10·22°; hence

10·22 heat-units will raise the temperature of 1 gr. of iron, 89·78 degrees.

$\therefore \left.\begin{array}{r}\frac{10{\cdot}22}{89{\cdot}78} \\ \text{or } {\cdot}1138\end{array}\right\}$ „ „ „ „ 1 degree.

The relative heat of iron is therefore ·1138.

If 1 gramme of mercury and 1 gramme of water at the same temperature are put into perfectly similar vessels and exposed to the same source of heat, the mercury becomes much hotter than the water does *in the same time.* Thus, if the initial temperature of each is 15°, and, after the lapse of one minute, the temperature of the mercury is 20°, that of the water will be 15·165°. Equal quantities of heat have been supplied *to each, viz.* ·165 unit of heat. This has raised the

temperature of the water ·165 of a degree, but that of the mercury 5 degrees. Now

$\because$ ·165 unit of heat will raise the temperature of 1 gr. of mercury 5 degrees.

$\therefore \left.\begin{array}{l}\frac{\cdot 165}{5} \\ \text{or } \cdot 033\end{array}\right\}$,, ,, ,, ,, 1 degree.

We arrive at the same number ·033 if we allow equal weights of mercury and of water at 100° to cool down to 15°; the water taking longer than the mercury in the proportion of 1 to ·033. This mode of determining the relative heat of a substance is called the *method of cooling*.

The relative heats of various substances have been found, the methods employed being three in number. (1) The "*method of cooling*" was proposed by Dulong and Petit, but it is not very accurate. (2) Lavoisier* and Laplace† constructed an apparatus similar to that represented in Figure 43. Three vessels, A, B, and C, were arranged as shown, the space between A and B and that between B and C being filled with ice. A certain weight, say 1·5 gramme of tin at 100°, was put into C, and C was then closed by a sheet of ice. The tin in C cooled down to 0°, melting the ice in B; this melted

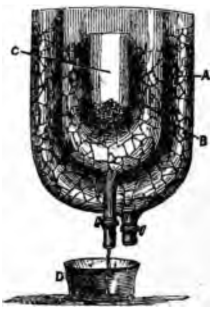

Fig. 43.

* Anthony Lawrence Lavoisier (1743—1794).

† *Peter* Simon, Marquis de Laplace (1749—1827).

ice ran down into the vessel D, and was carefully weighed after the experiment. The vessel, A, with its contained ice, was for the purpose of preventing any of the ice in B from being melted by the hot air of the room; the water that was formed from the ice in A was allowed to run off. Suppose that the quantity of water which ran into D was 106·7 milligrammes. Each gramme of ice melted requires 79 units of heat; hence 1·5 gramme of tin, in cooling from 100° to 0°, gives out (·1067 × 79) units of heat; *i.e.*

1·5 gramme in cooling 100 deg. gives out 8·43 units of heat.

$\therefore$ 1 gramme „ 100 „ „ $\frac{8 \cdot 43}{1 \cdot 5}$ „

$\therefore$ 1 gramme „ 1 „ „ $\frac{8 \cdot 43}{150}$ „

$= \cdot 0562$ „

and the relative heat of tin is ·0562. This method also is objectionable, because it is very difficult to collect *all* the water that is melted. (3) The third method is that known by the name of the "*method of mixtures:* a certain weight of water at a known temperature is mixed with a certain weight of the substance to be examined at some other known temperature; the two are well agitated together, and the temperature of the whole is observed. Several corrections, as already indicated, have to be made; but Regnault succeeded, by means of an elaborate apparatus, in obtaining the following numbers which he regards as approximately accurate.

Name of substance.	Relative Heat.
Water	1·0000
Crystallised boron	·25
Liquid phosphorus	·212
Glass	·19768
Crystallised silicon	·1774
Diamond	·14687
Iron	·1138
Brass	·09391
Silver	·057
Tin	·0562
Iodine	·0541
Mercury	·0332
Lead	·03065

Questions on Relative Heat.

1. A gramme of ice at 0° requires a greater weight of mercury at 100° than of water at 100° to melt it completely. Why so? What weight of mercury at 90° will melt 3 grammes of ice at 0°?—*Ans.* 79·317 grammes.

2. How much longer does water take to cool from 100° to 80° than an equal weight of boron?—*Ans.* Four times as long.

3. 40 kilogrammes of boron at 50° are mixed with 20 kilogrammes of water at 15°. The temperature of the water is found to be 26·7°. Find the relative heat of boron.

The *boron cools* 23·3 degrees; this is equivalent to

40 times 23·3 kilogrammes cooling one degree. The quantity of heat given out has heated the water 11·7 degrees, or has heated 20 times 11·7 kilogrammes of water one degree. Hence 234 units of heat will raise the temperature of 932 grammes of boron one degree.

4. 15 grammes of silver at 90° are agitated with 10 grammes of water at 10°, and the temperature of the water is found to be 17·089°. Find the relative heat of silver.

5. 50 grammes of silicon at 80° are mixed with a kilogramme of water at 10°. Find the temperature of the mixture after agitation.

In working out examples of this kind, it is very convenient to suppose that the hotter body cools down to the temperature of the other body, and that the heat thus given out is afterwards divided between the two in such proportion as to raise the temperature of each body to an equal extent.

Now 50 grammes of silicon cooling from 80° to 10° is equivalent to 50 × 70 grammes, or 3·5 kilogrammes cooling one degree; but, from the table of relative heats, we see that 1 kilogramme of silicon cooling one degree evolves 177·4 units of heat; hence the total quantity evolved is 3·5 × 177·4 or 620·9 units. Now this quantity has to be divided between a kilogramme of water at 10°, and ·05 kilogramme of silicon at 10°. The quantity of heat requisite to raise the temperature of the water one degree is 1000 units; the quantity required by the silicon is ·05 of 177·4, or 8·87 units. Hence 620·9 units must be divided between the water and the silicon in the proportion of *1 to ·00887*. The quantity received by the water is

therefore $\frac{620 \cdot 9}{1 \cdot 00887}$, and that received by the silicon is $\frac{620 \cdot 9 \times \cdot 00887}{1 \cdot 00887}$; these two quantities added together make up the total quantity, 620·9 units. The effect of $\frac{620 \cdot 9}{1 \cdot 00887}$ units of heat upon a kilogramme of water is to raise its temperature by about ·62 of a degree; the effect of the other quantity upon the silicon can be found, seeing that we already know that its temperature is raised one degree by 8·87 units of heat.

The following is a simpler way of solving the same problem. As before, 620·9 units of heat have to be applied to a mixture of 50 grammes of silicon and 1000 grammes of water, both at 10°. Now the quantity of heat required to raise the temperature of 50 grammes of silicon one degree is 50 × ·1774, or 8·87 units of heat; and the quantity required by the water is 1000 units. Hence the temperature of the mixture is raised one degree by (1000 + 8·87) or 1008·87 units of heat. Therefore, by 620·9 units, the temperature is raised $\frac{620 \cdot 9}{1008 \cdot 87}$, or ·615°; and as the initial temperature is 10°, the answer is 10·615°.

6. A kilogramme of mercury at 100° is agitated with 50 grammes of water at 20°. Find the temperature of the mixture.—*Ans.* 51·9°.

7. 35 decagrammes of lead at 80° are agitated with 10 cubic centimetres of water at 4°. Find the temperature of the mixture.—*Ans.* 43·3°.

8. A glass bottle, weighing 1·5 kilogramme, contains a kilogramme of mercury at 70°; 15 deci-

grammes of water at 20° are then put into the bottle, and the whole is well agitated. What is the temperature, after agitation, of any one of the substances used, supposing that none of the heat passes into the air?—*Ans.* 69·8°.

It is easy to make examples for one's self in this subject since the answers are readily verified. After having worked out a sum like the following:—3 grammes of water at 15° are mixed with 3·5 kilogrammes of mercury at 40°: find the temperature of the mixture —another question can be immediately made up, which will verify the answer first obtained, viz. 3 grammes of water at 15°, after agitation with 3·5 kilogrammes of mercury at 40°, are found to be at the observed temperature: find the relative heat of mercury.

It has been assumed in the previous examples that the relative heat of a body is an invariable quantity as long as the body remains in the same physical state; this, however, is not the case. The relative heat of water at 50° is 1·0042, and at 100° it is 1·013; and the same increase in relative heat with rise of temperature is observed in all solid and liquid bodies. The higher the temperature the greater is the quantity of heat requisite to effect change of temperature, together with the other simultaneous changes. This increase in the relative heat of a body might have been foreseen as a theoretical probability from the fact that the rate of expansion increases with rise of temperature; and, as a greater amount of expansion occurs in most liquids and solids between 90° and 91° than between 0° and 1°, a *greater* quantity of heat is required to effect it.

Dulong and Petit were the first to observe this variation in the relative heat of a body. The same philosophers established a most important law, which will be comprehended by those who have studied chemistry. If, instead of taking the relative heats of equal weights of the several elements, phosphorus, iron, silver, tin, iodine, mercury, and lead, we find the relative heats of the under-mentioned weights of these elements, we observe that we have an almost constant quantity—the average being 6·5 nearly.

	Relative heat of		
Phosphorus	31 grammes	= 6·572	(= 31 × ·212)
Iron	56 ,,	= 6·37	
Silver	108 ,,	= 6·16	
Tin	118 ,,	= 6·63	
Iodine	127 ,,	= 6·87	
Mercury ...	200 ,,	= 6·66	
Lead.........	207 ,,	= 6·35	

Boron (11 grammes), carbon (12 grammes), and silicon (28 grammes) are exceptions to Dulong and Petit's law. From the above we see, *e.g.* that 108 grammes of silver require as much heat to raise their temperature one degree as do 127 grammes of iodine; and 108 grammes of silver combine chemically with 127 grammes of iodine, forming 235 grammes of silver iodide. Again, 207 grammes of lead require the same quantity of heat (6·4 units); and 207 grammes of lead combine chemically with twice 127 grammes of iodine, forming 461 grammes of lead iodide. The numbers above given (6·572, &c.) are called *Atomic Heats*, or the relative heats of atoms. (Compare *Barff's Chemistry*, Part II. Chap. II.)

If we wish to know the relative heats of equal volumes of the various substances already mentioned, we must multiply the relative heats of equal weights (page 141) by the relative weights of the several substances; for one body is as much bulkier than another as the relative weight of the former is less than that of the latter. The relative heat of 1 cubic centimetre of water at 4° is taken as 1·0; and that of 1 cubic centimetre of mercury at 0°, or of 13·596 grammes of mercury, is ·0332 × 13·596.

It is to be observed that, of all substances hitherto mentioned, water has by far the highest relative heat; that of ice (taken between —80° and 0°) is about ·474. This will account for many well-known facts. If the relative heat of water were very low, all natural waters would rapidly become very hot in the summer and very cold in the winter. In summer, the seas and rivers receive a great quantity of heat from the sun, but their temperature rises only very slightly; most of the heat goes to effect other changes than that of temperature, and is converted into potential energy. In winter, this great quantity of heat is recovered again, the water becoming very gradually colder. Hence, during the summer months, the sea is colder than the land; but, during the winter months, the sea is warmer than the land. This is the cause of the monsoons mentioned in a previous chapter; and, if we substitute day and night for summer and winter, we have the cause of land and sea breezes. (Page 83.)

If two short bars, one of bismuth and the other of iron, are placed upright on the lid of a vessel full of *hot water,* their other extremities being coated with

wax, it will be observed that the wax on the bismuth is the first to melt. But, if the reader refers to page 28, he will see that bismuth is not so good a conductor of heat as iron is. The iron transmits a greater quantity of heat than the bismuth does; but, since the relative heat of iron is ·1138 and that of bismuth ·03084, the iron would have to transmit ·1138 unit of heat for every ·03084 unit of heat transmitted by an equal weight of bismuth, in order that its temperature might be the same as that of the bismuth at any given distances from the source of heat. "It is usually stated, that the greater the *quickness* with which the wax melts the better is the conductor. If the bad conductor and the good conductor have the same specific heat,* this is true; but in other cases, it may be entirely incorrect. The proper way of proceeding is to wait until both the iron and the bismuth have attained a constant temperature" †; it is then found that heat is transmitted a greater distance along the iron than along the bismuth bar.

Miscellaneous Questions.

9. Explain the cause of the inaccuracy observed in the mercurial compensating pendulum (page 20).

10. Explain fully why the low relative heat of mercury renders that element very well adapted for thermometric purposes.

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* See p. 138.

† *Tyndall*, "Heat as a Mode of Motion," pp. 233-4.

11. Show how the temperature of the earth is affected by the presence of ice, water, and steam.

12. How should we be affected if the relative heat of everything were equal to that of water?

13. Platinum expands very nearly to the same extent between 0° and 100°, 100° and 200°, 200° and 300°, &c. How should we expect its relative heat to be affected by rise of temperature?

14. What weight of lead at 100° will raise the temperature of a kilogramme of water to the same extent as will 56 grammes of iron at 100°?

II.—Of Gases.

Theoretical considerations would lead us to foresee, not only that equal volumes of all perfect gases require equal quantities of heat to raise their temperature by one degree (page 136), but also that the quantity of heat required to raise the temperature of, say, 1 gramme of a gas from 0° to 1° is equal to the quantity required to raise the temperature of *an equal weight* from 90° to 91°, or from 150° to 151°, because the amount of expansion undergone is the same in all cases (page 75). One litre of a gas, measured off at 100°, would require less heat to raise its temperature to 101° than would one litre of the same gas, measured off at 0°, when heated to 1°; because the amount of expansion undergone in the former case is only 1-373rd of a litre, whereas the amount of expansion in the latter case is 1-273rd of a litre. Suppose that one litre of the gas is measured off *at 0°, and that* the quantity of heat required to raise its

temperature to 1° is accurately noted; if this litre is then heated to 100°, it will be found to occupy a volume of $1\frac{100}{273}$ or 1·3665 litre. This volume at 100° will require the same quantity of heat to raise its temperature to 101° as was required by the 1 litre at 0°, in order that its temperature might rise to 1°. But we must not expect to find such perfect regularity with those gases which do not obey Gay-Lussac's law of expansion.

We can determine the relative heat of a gas under various conditions. I. The gas may be allowed to expand, the pressure upon it being constant; II. The gas may be kept at constant volume, the pressure being so varied as to effect this: and, in each case, we may determine the relative heats of equal weights, or of equal volumes, of the several gases. We divide the subject, therefore, as follows:—

RELATIVE HEATS OF GASES	I. *At constant pressure*	1. Of equal weights.
		2. Of equal volumes.
	II. *At constant volume*	1. Of equal weights.
		2. Of equal volumes.

The relative heats of equal weights of the various gases at constant pressure are determined in the following way. A certain known weight of the gas to be examined is heated to a certain known temperature, and is then made to pass through a spiral tube, surrounded with a known weight of water at a previously ascertained temperature; as the gas issues from the tube, its temperature is again observed. The water is well agitated throughout the experiment, and the increase in temperature undergone by it is accurately

noted by means of a very sensitive thermometer. Suppose that 10 grammes of a gas at 100° passed through the tube, issuing from it at 20°; that the tube was surrounded with 100 grammes of water at 15°, and that the temperature at the end of the experiment was 17°, allowing for the heating of the tube itself, of the thermometer, the containing vessel, the rod employed for stirring the water, and for various other causes of inaccuracy. From these data we deduce the relative heat of the gas, thus:—

The quantity of heat gained by the water is 200 units of heat.
∴ 200 units of heat are required to raise the temperature of
10 grammes of the gas 80 degrees,
or 800 „ „ 1 „
∴ $\frac{200}{800}$ „ 1 „ „ 1 „
i.e. $\frac{1}{4}$, or ·25 is the relative heat required.

In this way it has been found that the relative heat of hydrogen is 3·409; *i.e.* that 1 gramme of hydrogen at 0°, in order that its temperature may rise to 1°, requires a quantity of heat sufficient to raise the temperature of 3·409 grammes of water from 0° to 1°, if the hydrogen is allowed to expand. Under the same conditions, the relative heat of oxygen is ·2175. If the pressure upon the gases is constant, then

1 gramme of hydrogen requires 3·409 units of heat for its temperature to rise from 0° to 1°,
and 1 „ oxygen „ ·2175 „ „

Now, if, instead of *equal weights* of these gases, we wished to consider *equal volumes* of them, we should *have to take* 1 gramme of hydrogen and 16 grammes

of oxygen, both of which occupy equal volumes *under the same conditions of temperature and pressure.* Hence, at 0° ·76m. barometric pressure,

11·2 litres of hydrogen require 3·409 units of heat for their temperature to rise from 0° to 1°,
and 11·2 „ oxygen „ ·2175×16 „ „

Hence, to find the relative heats of equal volumes, we must multiply the relative heats of equal weights by the relative weights of the respective gases (see pages 84 and 146). The following table contains the results of experiments made in the way described on page 149, and also the calculated results for equal volumes :—

RELATIVE HEATS OF GASES AND VAPOURS AT CONSTANT PRESSURE.

Gas.	Equal weights.		Equal volumes.
Hydrogen	3·409 ...	× 1	= 3·409
Oxygen	·2175 ...	× 16	= 3·48
Nitrogen...........	·2438 ...	× 14	= 3·4132
Air	·2374 ...	× 14·45	= 3·4304
Nitrous oxide......	·2238 ...	× 22	= 4·9236
Nitric oxide	·2315 ...	× 15	= 3·4725
Carbonic oxide ...	·245 ...	× 14	= 3·43
Carbonic acid	·2163 ...	× 22	= 4·7586
Sulphurous acid...	·1544 ...	× 32	= 4·9408
Hydric chloride ...	·1845 ...	× 18·25	= 3·3671
Steam	·4805 ...	× 9	= 4·3245

The last column of figures exhibits a regularity that we expected to find. The only discrepancies—nitrous oxide, carbonic acid, sulphurous acid, and steam—are such as do not invalidate what we have previously said; heat has to do more work in causing these gases to become hotter, and hence equal volumes of them have a higher relative heat. Putting these, therefore, on one side, we see that the relative heats of the rest range from 3·3671 to 3·48; such irregularity is by no means surprising when we consider the experimental difficulties and the number of uncertain corrections that have to be made, in determining the relative heats of equal weights.

The 3·409 units of heat, in the case of hydrogen (and the other gases will furnish similar examples), are employed for two different purposes; one portion of this quantity of heat raises the temperature of the 11·2 litres of hydrogen from 0° to 1°, and the remainder is used up in forcing away the atmosphere to a certain extent. Now, if the hydrogen, whilst being heated, was not allowed to expand, the heat would have only to raise its temperature; there would be no external pressure to be overcome, no work to be performed, and therefore a less quantity of heat would be required. Hence, the relative heats of gases at constant volume must be less than the relative heats of the same gases at constant pressure. This has been proved experimentally; in the following table, the first column of figures is the result of experiment, and the second column is derived from the first in the same way as before, viz. by multiplying the relative heat (of equal weights) of each gas by the relative weight of the gas.

RELATIVE HEATS OF GASES AND VAPOURS AT CONSTANT VOLUME.

Gas.	Equal weights.		Equal volumes.
Hydrogen	2·406	...	2·406
Oxygen...	·155	...	2·48
Nitrogen	·173	...	2·422
Air	·168	...	2·419
Nitrous oxide	·18	...	3·96
Nitric oxide	·165	...	2·475
Carbonic oxide	·173	...	2·422
Carbonic acid	·171	...	3·762
Sulphurous acid	·121	...	3·872
Hydric chloride	·131	...	2·391
Steam	·369	...	3·321

The important conclusion that is to be derived from this table will be given in the next chapter. In the meantime, we must observe that, of the 3·409 units of heat above referred to, 2·406 units of heat raise the temperature of 11·2 litres of hydrogen from 0° to 1°; the remainder (1·003 units) is employed in overcoming external pressure, and becomes converted into potential energy.

EXAMPLE 1. 120 grammes of carbonic oxide at 90° are passed through a tube surrounded with 1 kilogramme of water at 0°. The gas issues from the tube at 40°. What will be the temperature of the water, disregarding the heating of the tube, &c.—*Ans.* 1·57°.

2.* How much heat is required to raise the temperature of a cubic metre of nitric oxide from 0° to 50°?—*Ans.* 15502 units of heat nearly.

3. How much heat is required to raise the temperature of a cubic metre of oxygen from 50° to 100°?—*Ans.* 13130·8 units nearly.

4. What weight of water could be heated from 15° to 35° by the heat given out during the cooling down of 80 grammes of sulphurous acid from 100° to 35°?—*Ans.* 40·144 grammes.

5. 3 grammes of carbonic oxide at 20°, 5 litres of nitrogen at 27°, and 10 grammes of hydrogen at 15° are mixed together. What will be the temperature of the mixed gases?—*Ans.* 15·56°.

6. Calculate the relative heat of air at constant pressure from those of oxygen and nitrogen,—air being a mixture of oxygen and nitrogen in the proportion of 21 to 79 by volume, and 23 to 77 by weight.

7. What is the relative heat of a mixture of equal volumes of nitrous oxide and carbonic oxide?—*Ans.* ·232.

8. Find the relative heat of a mixture of 1 volume of oxygen to 2 volumes of hydrogen?—*Ans.* ·5721.

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* In the following examples, the atmospheric pressure is supposed to be equal to that of a column of mercury 760 millimetres high at 0°.

CHAPTER X.

NATURE OF HEAT.

The accompanying figure (Fig. 44) represents a hollow vessel of which the section A B C D, or E F G H, &c., is a square decimetre in area. The portion E C is filled with air at 0°, and we will suppose that E C has a capacity of 11·2 litres. This air is shut out from the external air by a piston, the lower surface of which is represented by E F G H. Let the pressure of the atmosphere upon this piston be equal to that of a column of mercury 760 millimetres high when the barometer is reduced to 0°. This pressure is equal to 103·33 kilogrammes on the square decimetre; we must therefore regard the atmospheric pressure as a weight of 103·33 kilogrammes on the piston E G, since its area is a square decimetre. The weight of the air in E C, its bulk being 11·2 litres at 0°·76m. B. P., is 14·4 grammes. Since E C is 11·2 litres or cubic decimetres, and A B or B C is a decimetre, it is evident that E A or D H must be equal to 11·2 decimetres.

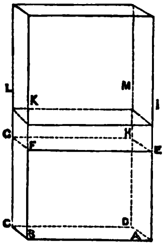


Fig. 44.

The gas is now heated from 0° to 1°, the pressure remaining constant. The quantity of heat required for this purpose is nearly 3·4 units; and the gas expands, occupying, we will suppose, the volume I C. The bulk of 11·2 litres, measured off at 0°, when heated to 1°, is 11·2(1 + ·00367) or 11·241 cubic decimetres; I C is therefore 11·241 cubic decimetres. As before, I A or M D is 11·241 decimetres in length; hence I E or M H is (11·241—11·2) or ·041 decimetre.

If the gas is heated without being allowed to expand, the quantity of heat required is nearly 2·4 units. Of the 3·4 units before required, 2·4 raised the temperature from 0° to 1°, while the rest (1 unit) was used up in causing expansion, *i.e.* in raising a weight of 103·33 kilogrammes through a height of ·041 decimetre or ·0041 metre.* This is evidently the same as raising a weight of 10·333 *grammes* through a height of 41 metres, or the same as raising, to a height of 1 metre, a weight of (10·333 × 41) or 423·653 grammes. And this, therefore, is the number of grammes that could be raised 1 metre from the earth's surface by the expenditure of a quantity of heat sufficient to raise the temperature of 1 gramme of water from 0° to 1°. The 1 unit of heat has been converted into potential energy; for a stone has more potential energy when it is 1 metre above the earth's surface than when it is lying on the ground.

Several highly interesting considerations are intimately connected with the above demonstration. We see

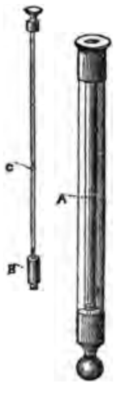
* This, it will be seen, is an assumption; since there may be *internal* work going on in the gas, as in the case of vapours.

that, when a gas expands, it does work, just as a horse does work when it pulls a waggon up a hill; in the former case, there is an expenditure of heat, while, in the latter case, there is an expenditure of a certain amount of muscular force. Gaseous expansion, therefore, is accompanied with refrigeration or disappearance of heat, and the cause of this apparent destruction of heat is the necessary production of potential energy. A gas, in order to do work, requires heat, just as a horse, to do work, requires food. If the receiver of an air-pump is filled with moist air and is then exhausted in the ordinary way, the air within the receiver becomes colder, and the aqueous vapour consequently condenses, forming a cloud in the receiver. In this case, the air expands when the piston is moved in the cylinder; but it does not do the whole of the work, for the arm of the experimenter assists in the process. That it does do some of the work is evident from the fact that, when the receiver contains very little air indeed, it is far more difficult to raise the piston; and, indeed, it is almost impossible to raise it if the vacuum produced is very perfect and the area of the piston sufficiently great. The air, then, does work when the receiver is exhausted; but, before it can do this work, it requires a certain quantity of heat. Since heat is not freely supplied to it, it uses up some of the heat it already has, and consequently becomes colder. Suppose (in Fig. 44) the piston E G is artificially raised until it occupies the position I L. The quantity of work done may be represented by 423 grammes being raised to a height of 1 metre, and the expenditure of heat for this purpose is 1 unit of heat. A portion of this expen-

diture takes place in the arm of the experimenter; the rest is supplied by the gas in E C, which consequently becomes colder. If we now leave go of the piston-rod, the atmospheric pressure outside will force the piston back into its former position E G; that is to say, there will be a fall of 423 grammes through a height of 1 metre. But, just as it required the expenditure of 1 unit of heat to raise the above weight 1 metre high, so, when the same weight falls through a height of 1 metre, there is an apparent creation of 1 unit of heat. Only part of a unit of heat, it will be remembered, was withdrawn from the air, but a whole unit of heat is now imparted to it, so that it is hotter after than it was before the experiment; it has received not only the heat which was supplied by itself, but also that which was supplied by the experimenter's arm. Thus, when a man labours, the strength of his body is gradually used up; it is not, however, destroyed, but is converted into heat. Our observations of natural phenomena tend to show that all varieties of energy become converted sooner or later into heat. The axial, as well as the orbital, movement of the earth is gradually diminishing—the forces which produce these movements being changed into an equivalent amount of heat. Such considerations as these, however, are beyond the limit of the present work; we must, therefore, refer the student, who may wish to pursue them, to more advanced works on the subject.

Disappearance of heat accompanies gaseous expansion; evolution of heat accompanies gaseous compression. These two facts have been employed to explain the variations in atmospheric temperature observed when we rise higher and higher from the earth's

surface. The air at the level of the sea receives heat from the warm earth and expands, but does not become colder on that account, because heat is freely supplied to it from the earth; being now relatively lighter than the air above, it rises from the earth's surface. Suppose that it has risen to a height of 1 kilometre; the pressure upon it is much less, and it therefore expands until the pressure exerted by it is equal to the pressure of the superincumbent atmosphere upon it. It expands and forces back the pressure of the atmosphere above, thus performing work and occasioning an expenditure of heat. Consequently, it becomes colder as it rises, and, though, at the sea level, its temperature may be 25° or 30°, it is reduced to 0° at a comparatively short distance above that level.



A. Glass Syringe.
B. Leather Piston.
C. Metallic Piston-rod.

Fig. 45.

The conversion of mechanical force into heat is well seen in the experiment with the Fire Syringe. This instrument (Fig. 45) is a stout glass cylinder, provided with a tightly-fitting piston. When the latter is suddenly pushed down so as to compress the air within the syringe, the mechanical force employed becomes converted into heat, and this heat is sufficient to ignite a piece of tinder placed inside. It seems as if the heat produced were forced or pressed out of the air in the syringe; but the most accurate experiments made by Regnault have proved that the quantity of *heat* in any weight of a gas is independent of the pressure to which it is subjected.

Gas can be caused to expand without having to repel any external pressure, as in the following experiment first made by Gay-Lussac, and repeated in our own times by James Joule. The vessel A (Fig. 46) is filled with a great quantity of air under high pressure, and is connected by means of a tube provided with a stop-cock with another vessel B, which is exhausted of its air. Now, when the stop-cocks are turned so as to allow the gas in A to expand into the vessel B, there is no external pressure to be overcome. The particles in A that are at a distance from the stop-cocks drive forward the other particles, and consequently do a little work; the particles thus impelled are driven into B, when their energy of motion is converted into heat. Hence the gas in A falls in temperature, but the temperature of the gas in B rises to the same extent; so that, when mixed, the gas appears to have undergone no change of temperature, though the bulk has been greatly increased.

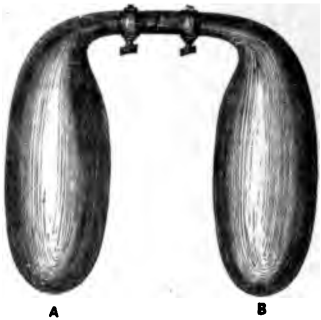


Fig. 46.

The relative heat of a gas at constant volume may be found roughly in the following way :—In Figure 44 suppose that the 14·4 grammes of air are heated from 0° to 1° under a constant pressure of ·76m. B. P. The quantity of heat required is about 3·4 units. If the gas

is now forcibly compressed until it occupies the same volume as before it was heated (11·2 litres), it will be found to become hotter; its temperature, after compression, will be nearly 1·4°, supposing that none of the heat is lost, or is absorbed by the containing vessel. The quantity of heat that was converted into potential energy has been reconverted into heat, and has been imparted to the gas. Hence 3·4 units of heat will raise the temperature of 11·2 litres of air, measured off at 0°·76m. B. P., from 0° to 1·4°, or through 1·4 degrees; therefore $\frac{3\cdot4}{1\cdot4}$, or 2·4 units of heat will raise the temperature of the same weight of air 1 degree—*when the volume is constant.* This method is not, of course, at all accurate, because the containing vessel is heated as well as the piston.

Let us pass now to the consideration of the weight (423 grammes) that was raised 1 metre high by the expenditure of 1 unit of heat. Suppose that the above weight was projected vertically upwards so as to reach to a height of 1 metre; when it is at that height above the earth's surface, in what respect does it differ from a similar weight resting upon the earth? A certain amount of force (equivalent to 1 unit of heat) has been employed to raise it 1 metre high; what has become of that force? In Fig. 47, let A represent the weight 1 metre high, and B the weight at the earth's surface. A differs from B in point of *position:* and, in virtue of its position, it possesses something that B does not possess, viz. the power of falling through a distance of 1

Fig. 47.

metre. This possible power is called *potential energy* or *energy of position.* Suppose that A now falls to the point C; in this position it will differ from B inasmuch as it still possesses a certain amount of potential energy; but, when it reaches C, it is in a state of motion, and has therefore undergone a change within itself. At C it has not only energy of position, but also *energy of motion* or *kinetic energy.* This kinetic energy has been produced by the conversion of a certain amount of potential energy. Finally, when A reaches the earth's surface, it has no energy of position, for all of this has been converted into kinetic energy. But it is found that, when a weight of 423 grammes is projected up in the air with a force that is equivalent to 1 unit of heat, neither does the weight rise to the height of 1 metre, nor is 1 unit of heat produced when the ball strikes the earth; the height attained is a little less than 1 metre, and the heat produced is a little less than one unit. This slight inaccuracy is occasioned by the friction of the weight against the air; when rising and falling, the weight has a certain amount of its kinetic energy converted into heat on account of the partial stoppage of its motion by the air, just as the whole of its kinetic energy is converted into heat when its motion is entirely stopped by the earth.

Friction is a powerful means of converting mechanical force into heat. Rumford* was the first to calculate the quantity of heat produced when two substances were rubbed together with a certain amount of force.

* *Benjamin* Thompson, Count Rumford (1753—1814).

When boring cannon at Munich, he observed that the water employed to keep the cannon cool was considerably raised in temperature. He then caused a cannon of known weight to revolve on a rough steel borer, and the heat given out went to raise the temperature of a known weight of water at 0°. The force employed to turn the cannon being measured, and the quantity of heat imparted to the water and to the cannon being observed, Rumford assumed that the latter was produced by the expenditure of the former, and was therefore equivalent to it.

It has been urged that too much was assumed, seeing that the heat might have been occasioned by a diminution in the relative heat of the brass, and that the chips of metal separated during the process might have had a lower relative heat than the substance of the cannon. But Rumford was careful to show that no such change takes place in the relative heat. Further, an ingenious experiment performed by Sir Humphry Davy has placed the matter beyond all doubt; he succeeded in melting two pieces of ice by rubbing them together in vacuo, at the same time preventing the access of external heat. The water produced in this experiment has a much higher relative heat than the ice; hence the potential heat which caused the ice to melt must have been obtained by the conversion of the mechanical force employed for the friction.

James Joule has determined the quantity of heat occasioned by the friction of two substances with the utmost accuracy. A paddle-wheel, furnished with vanes, was made to revolve in a copper vessel between stationary vanes; a weighed quantity of water at a known

temperature was placed in the vessel, and the temperature was determined after the paddle-wheel had revolved for a certain time. The force employed to turn the wheel was known; and corrections were made for the heating of the copper vessel, of the wheel itself, &c. In this experiment, the heat was occasioned by the friction between the vanes and the water. Similar experiments were made with oil and mercury, with two solids, as iron and brass, &c.; and it was found that, in all cases, the expenditure of an amount of force represented by the fall of 423 grammes through a height of 1 metre occasioned the evolution of 1 unit of heat. This, therefore, is the mechanical equivalent of the unit of heat.

Since, then, motion of any kind can be converted into heat, and heat can be converted into motion (as in the case of the Steam Engine for example), and since, moreover, a certain quantity of motion and a certain quantity of heat are exactly equivalent to each other, it is now almost universally admitted that heat is nothing more than a peculiar kind of motion; but it is motion of the constituent particles, not of the mass as a whole. The particles are supposed to vibrate; and the hotter the body is, the more rapidly do the particles vibrate. When heat is converted into mechanical force, the motion of the particles is imparted to the mass.

CHAPTER XI.

CONNECTIONS BETWEEN THE SCIENCES OF HEAT AND CHEMISTRY.

Chemical Force is the force that tends to make two substances, like carbon and oxygen, combine. Phosphorus has a great tendency to combine with iodine*; the particles of the one rush, as it were, towards those of the other and combination takes place. The motion of chemical force is here converted into the motion of heat. When carbon combines with oxygen, the heat produced by the conversion of the chemical force existing in the elements is so great as to give rise to the phenomena of combustion. Heat is always evolved during combination, because the chemical force that gives rise to the combination is always converted (at least partially) into heat;—we say *partially;* for, in many cases, a portion

* In chemical works it is generally stated that substances which combine have an *affinity* for one another; whereas substances, between which there is affinity, do not usually combine. This error is occasioned by the total misapplication of the term "affinity." There is the greatest *chemical affinity* between nitrogen and phosphorus; but these two elements will not combine together *directly;* and it is at least doubtful whether any compound of the two has ever been obtained even by *indirec processes.*

of the chemical force is converted into *electricity*, and sometimes also into light. In a former chapter, the potential energy of steam was compared with that of coal; we now see that the potential energy of coal is nothing more than chemical force.

When quicklime is treated with water, the two combine and a great quantity of heat is evolved; in order to separate the quicklime and water again, we have to heat the compound, during which process a certain quantity of heat disappears—equal to the quantity evolved during the previous combination. In this case, not only is a certain amount of chemical force equivalent to a certain amount of heat, but also these two forces are directly convertible the one into the other. This, however, is not always the case: for instance, a gramme of carbon evolves a certain definite quantity of heat when it burns in oxygen, and carbonic acid is formed; but this carbonic acid cannot be decomposed into carbon and oxygen by the agency of heat alone.

The following table gives the number of units of heat evolved when 1 gramme of each substance named is burnt in excess of oxygen.

Substance.	Heat of combustion in Oxygen.
Hydrogen	34,000
Carbon	8,000
Phosphorus	5,750
Sulphur	2,250
Copper	600

When hydrogen combines with chlorine, 24,000 units of heat are evolved.

The *temperature of the human body* is maintained principally by means of combustion. In respiration, oxygen is inhaled into the lungs and enters into solution in the blood. Various obnoxious compounds, which have found their way into the blood, are decomposed (or partially *burnt up*) by this oxygen, and the bodies thus formed are given off; as, for example, exudation from the skin, carbonic acid from the lungs, &c. (See *Barff's Chemistry*, pp. 59, 60.) A portion of the heat in the animal body, however, is accounted for by the friction between the blood and the blood-vessels.

The *sun* is now universally regarded as the original source of all terrestrial energy. The sun itself is an intensely hot mass, surrounded by its *Atmosphere*. The latter consists of two portions; that which is next to the sun is called the *Photosphere*, or the light-giving atmosphere. Kirchoff supposed that the photosphere consisted of solid or liquid material, but Frankland and Lockyer have shown that it is most probably gaseous. It is encircled by another layer—the second portion of the sun's atmosphere—called the *Chromosphere*, which is about 8,000 kilometres high, and appears from the researches of Lockyer to consist mainly, if not wholly, of hydrogen. Owing to the gravitation of the central mass of the sun, the atmosphere is continually undergoing immense compression, which gives rise to the various forces that are radiated to us; and the researches of Lockyer have proved that the sun's heat is conveyed from the interior to the exterior by enormous currents (convection-currents) of gaseous matter.

Of the forces thus derived from the sun, the most evident are *Heat* and *Light*. But that the sun's rays

do not consist wholly of these two forces is apparent from observations first made by Sir John Herschel. He noticed that, when the sun's rays fell upon a solution of sulphate of quinine, a blue colour was produced on the surface of the liquid. Professor Stokes afterwards proved that this phenomenon is due to certain invisible rays which are absorbed by the sulphate of quinine and given off again as light-rays. These invisible rays are called *Chemical Rays*.

The forces emanating from the sun, then, consist, so far as our present knowledge goes, of Chemical Force, Light Force, and Heat Force. By special contrivances, these can be separated for the most part from one another; and Sir Isaac Newton* succeeded in breaking up the white light of the sun into rays of different colours. But there is *no essential distinction* between the above-mentioned kinds of force. When a wire of a pianoforte is made to vibrate, its motion gives rise to the sensation of sound; if it vibrates very much more rapidly, the motion is too rapid to produce this sensation; also, if it vibrates very much less rapidly, no sensation of sound is occasioned. The treble and the bass notes of a musical instrument are more inaudible than those which are produced by vibrations of intermediate rapidity. Heat, Light, and Chemical Force stand in the same relation to one another as inaudible bass notes, audible notes, and inaudible treble notes.

Plants are enabled, by the influence of the chemical force of the sun, to decompose the carbonic acid formed during respiration and combustion—the oxygen

* Sir Isaac Newton (1642—1727).

of the gas returning to the atmosphere, while the carbon is assimilated by the plant. This decomposition necessarily takes place only during the day. The chemical force of the sun is thus transferred to the carbon of plants and to the oxygen of the air. Plants, in the course of ages, become converted into coal (*Barff's Chemistry*, p. 28); hence, by the combustion of coal, we are actually converting into heat the chemical force that emanated centuries ago from the sun.

CHAPTER XII.

RADIATION OF HEAT.

Heat passes from one body to another in three different ways: first, by *conduction;* secondly, by *convection;* and thirdly, by *radiation.* We have already studied the conduction and the convection of heat.* The particles of a bar of iron have a peculiar movement due to heat. When the metal is heated at one end, the particles are thrown into more intense vibrations; this excess of motion gradually dies away along the bar. Let us take any one particle at the heated extremity; this particle is thrown into more intense vibrations than it had before, and causes the particle in front of it to vibrate more intensely than before, and so on. The gradual fall of temperature along the bar may be represented by a wave-line that gradually becomes less and less curved, as in Fig. 48, in which A represents the heated extremity and B that part of the bar which is at the same temperature as the surrounding air.

Fig. 48.

Now the question arises,—in what way does heat pass from the sun to the earth through

* See pages 26, 45, and 77.

an apparently unoccupied space? But natural philosophers have come to the conclusion that the space between the atmospheres of the sun and the earth is *not* unoccupied; it is supposed to be full of a peculiar substance called by them *Æther.** This æther is different from all other kinds of matter in respect that it is co-extensive with space, and does not obey the laws of gravitation—not being sensibly attracted by the earth or by the sun. It is by the vibrations of this peculiar substance that the forces of the sun are transmitted to us; the æther is thrown into a number of waves by the work going on in the sun, and some of these waves reach the earth. They are, of course, very variable in their nature; some are very long waves, others very short: the long waves are rays of heat; the very short waves are chemical rays; while the waves of intermediate length are rays of light.—Heat, Light, and Chemical Force are all peculiar kinds of motion.

If a hot iron ball is placed upon a stand in the middle of a room, it becomes cold in a short time, and in three different ways. If a lighted taper or the smouldering wick of a candle is held above it, a current of heated air will be observed to be passing upwards from the surface of the ball; part of the heat is being conveyed away by the air. The legs of the stand upon which the ball rests will be found to be hot; a portion of the heat is being conducted away. It will be noticed also that heat is being radiated from the ball in all direc-

* The diphthong is here used to distinguish this substance from *common ether.*

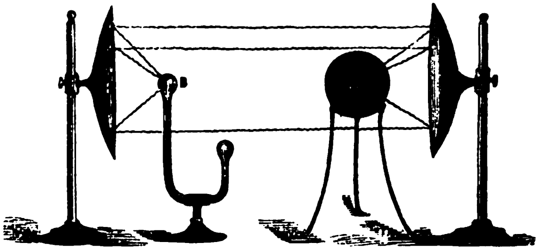


Fig. 49.

tions. If this radiant heat is allowed to fall upon a good *reflecting surface*, as represented in Fig. 49, the waves will be reflected at the surface of the reflector, and, if the reflector is of a certain shape, in parallel lines. These waves, that run parallel to one another, can be reflected again by means of a second reflector, and will collect at the point B, which is called the *principal focus* of the reflector. Now, if a thermometer or a thermoscope is placed at B, an immediate rise of temperature will be observed. If a piece of phosphorus is placed there, it will first of all melt and then ignite, but not if it is placed either nearer to the reflector or further from it. If a vessel containing water is placed at B, the water will become hotter and the iron colder, heat continuing to pass from A to B until both the ball and the water are at the same temperature. If the water is now replaced by a hotter body, heat will pass from B to A; if by a colder body, from A to B.

Now it is almost self-evident that the body at A (if at 100° we will suppose) will radiate exactly the same *quantity* of heat in all directions every minute whether

the body at B is at 50° or at 150°; but it will become colder in the one case and hotter in the other, while the body at B will become hotter if its temperature was 50°, colder if it was 150°. The reason of this is that, in the former case, more heat passes from A to B than from B to A; while, in the latter case, more heat passes from B to A than from A to B. It is therefore universally admitted that there is a continual exchange of heat going on between all bodies, even if they are at the same temperature; if they are not all at the same temperature, the hotter bodies radiate more heat than they receive and become colder, while the colder bodies radiate less heat than they receive and become hotter, until, at last, all are at the same temperature. This is called Prevost's Theory of Exchanges.

It has been ascertained by experiment that different substances have different powers of radiation. Fig. 50

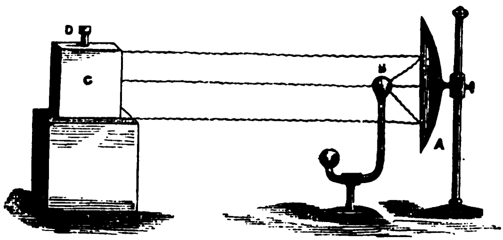


Fig. 50.

is an arrangement for showing this; A is a reflector, B a Leslie's thermoscope, and C a *Leslie's Cube.* This last piece of apparatus is a hollow vessel made of polished tin, and capable of containing hot water which is *poured in* at D; one of the vertical sides is coated

with lamp-black, another with paper, a third with glass, while the fourth side is left uncoated. When the side coated with lamp-black faces the reflector, the heat radiated from it is collected by the reflector and passes on to the bulb of the thermoscope, which is in the focus of the reflector. The effect is immediately observed by the column of liquid falling in the tube. When the side coated with paper faces the reflector, the liquid column is not depressed to so great an extent, showing that paper does not radiate heat so well as lamp-black does; the glass side produces still less effect upon the thermoscope, and the tin side scarcely any. Taking the radiation from lamp-black as 100, Leslie found that the radiation from paper was 98, and from polished tin or gold 12.

Good radiators of heat are found to be also good absorbers of heat. If this were not so, Prevost's Theory of Exchanges could not be correct; for, if lamp-black, for example, radiated heat with great facility but absorbed it with great difficulty, all specimens of that substance, when left sufficiently long exposed to other substances, would be found to be at a lower temperature than surrounding objects. A Leslie's Cube coated with lamp-black and filled with hot water becomes cold much quicker than if it had been left uncoated; but the same cube filled with cold water and exposed to the heat of the sun becomes hot much sooner if coated with lamp-black than if it is uncoated.

It is frequently supposed that the absorptive power of a substance for heat depends upon its *colour;* this, however, is not the case, except with the heat of the sun or of other bodies at very high temperatures.

A Leslie's Cube cools at the same rate whether it is coated with white or with black paper. The colour of winter clothing is immaterial so far as warmth is concerned, because the colour of the cloth does not affect the radiation of heat from the body; but, in summer, light coloured clothes should be worn because black cloth absorbs more heat than green cloth, green cloth more than red, and red more than white. Hence, in the east, the natives dress generally in white clothes.

That the absorptive power of a body for heat depends to a great extent upon the nature of the heat * is well seen in the following table given by Melloni:—

	Source of Heat.		
Absorbent.	Incandescent Platinum.	Copper at 400°.	Copper at 100°.
Lamp-black	100	100	100
White Lead	56	89	100
Shellac	47	70	72
Polished Metal	14	13	13

As the intensity of the heat diminishes, the absorption increases, except in the case of metals which are exceedingly bad absorbents of heat under all circumstances.

The *formation of dew* was first explained by Dr. Wells; other facts concerning it have been brought forward since by Melloni and Dr. Tyndall. Dew is observed to be deposited for the most part on grass and the leaves of trees; and there is always more dew on a clear still night than on a cloudy and windy one.

* So with light:—blue glass absorbs all light rays except those of blue light; red glass absorbs all but red rays, and so on.

The green parts of plants are very good radiators of heat; hence, after sunset, they become much colder than the air above, unless there are sufficient clouds to cause the radiated heat to return to the earth. The slightest covering over grass prevents the heat from being radiated, and therefore impedes the formation of dew. The air, in contact with these cold surfaces, becomes itself cooled, and the moisture it contains in the form of aqueous vapour is condensed directly the *dew point* (p. 121) is reached. A high wind will, of course, prevent any very considerable fall of temperature; it may even cause moisture already deposited to evaporate again, because air is rarely *saturated* with aqueous vapour.

Some substances absorb light, as black cloth; others reflect it, as looking-glasses, bright metallic bodies, &c.; and others, again, are transparent, *i.e.* they allow rays of light to pass through them. Glass is eminently transparent to light. So also with heat; some bodies absorb heat, others reflect it, and some are transparent to it. There is no substance of which we can say that it either absorbs, reflects, or transmits *all* the heat which impinges upon it; a good absorbent of heat (*e.g.* lamp-black) reflects a small quantity, a substance that transmits heat with facility will always absorb a little, and so on. Glass is very transparent to the heat which reaches us from the sun, but it is very opaque to the heat of an ordinary fire. Hot-houses are made of glass, so that the sun's heat may be able to penetrate into the enclosure, and become absorbed by the plants, earth, &c. But, when this absorbed heat is radiated from the plants, it will no longer penetrate the glass, *but is reflected* back, and hence the heat accumulates.

Glass screens are used for fires; they allow the light, but not the heat, of the fire to pass through them. The following table gives the percentage of heat-rays transmitted through a plate (2·6 millimetres thick) of each substance named :—

	Source of Heat.		
Substance.	Incandescent Platinum.	Copper at 400°.	Copper at 100°.
Rock Salt	92	92	92
Rock Crystal	28	6	3
Iceland Spar	28	6	0
Plate Glass	24	6	0
Ice	·5	0	0

The next table gives the transparency of liquids for heat :—

Stratum of Liquid 9 millimetres thick.	Source of Heat, Argand oil lamp.
Carbonic Disulphide	63
Ether	21
Hydric Sulphate	17
Hydric Nitrate	15
Alcohol	15
Hydric Acetate	12
Water	11

Dr. Balfour Stewart discovered the interesting fact that rock salt, which is so transparent to ordinary heat, is very opaque to the heat radiated from a heated mass of rock salt; the heat which is radiated from rock salt is absorbed by rock salt. Other philosophers have *shown that the* same is true of light; a vapour absorbs

the same kind of light as that which it emits when it is incandescent.

It will be seen that a substance may be very transparent to light, and yet opaque to heat. Ice and water are examples of this. In the same way, a body may be very transparent to heat (or *diathermic*, as it is called), and yet opaque to light. Dr. Tyndall discovered that a solution of iodine in carbonic disulphide was very diathermic, but did not allow the passage of light rays. Most gases are transparent to light; but their action on heat is very different. The yellowish-green gas, chlorine, is much more transparent to heat than the perfectly invisible gas, ammonia. The following table gives the absorptive power of several gases for the heat from a Leslie's Cube at 100°; the column of gas employed was about 1·2 metre long, and it was at a pressure of 760 millimetres of mercury :—

Air	1
Oxygen	1
Nitrogen	1
Hydrogen	1
Chlorine	39
Hydric Chloride	62
Carbonic Oxide	90
Carbonic Acid	90
Nitrous Oxide	355
Hydric Sulphide	390
Sulphurous Acid	710
Ethylene	970
Ammonia	1195

Dr. Tyndall, from whose work the above table is

taken, has ascertained that, with gases, good absorbers are also good radiators; moreover, that carbonic acid is particularly opaque to the heat from the carbonic oxide flame, which consists of incandescent carbonic acid. Aqueous vapour is very opaque to heat, especially to the heat radiated from a hydrogen flame which consists of incandescent steam.

The experiments of Dr. Tyndall tend to show that elementary bodies are more diathermic than compounds. This is especially the case with gases, the diathermancies of which have been given. The opaque vapour of bromine, an element, is far more diathermic than ethylene, a colourless compound gas. *Lamp-black*, which is a modification of the element carbon and is very *adiathermic* (opaque) to heat of high intensity, is diathermic to heat issuing from a source of 100°; but *ozone*, a modification of oxygen, is very adiathermic to heat issuing from a similar source.

The student should carefully distinguish between the passage of heat through a substance and the heat of the substance itself. When a substance is transparent to heat, the æther which permeates the substance vibrates with heat-waves, but these vibrations are not imparted to the substance; the æther vibrates independently of the substance. When, however, the heat is absorbed, the vibrations of the æther are transferred to the particles of the substance, and, consequently, the temperature of the latter rises. For instance, if a tube containing ether is held in the focus of a burning mirror, the temperature of the ether rises but slightly; because the heat-waves passing through the liquid are

only very partially transferred to the liquid particles. But, if the heat is caused to be absorbed, as by immersing in the ether a little lamp-black, the temperature of the liquid rapidly rises—the heat-waves are transferred to the liquid particles—and the ether boils away rapidly. (*Miller's Physics.*)

GENERAL QUESTIONS.

How are the measures of length, bulk, and weight interconnected?

Describe accurately the unit of weight. Why was this unit chosen?

A room is 7 metres square and 1 decametre high. Find the capacity of the room in cubic metres and in litres.

Why is the term *cold* usually excluded from scientific treatises on heat?

The temperature of a body meaning the tendency of that body to impart its heat to other bodies, show that all the objects in a room, if left quiescent for a sufficiently long time, must be at the same temperature.

Explain the apparent coldness of certain bodies.

What is meant by expansion? Give examples of it.

What other forces besides Heat will cause bodies to expand? Describe experiments to prove what you say.

What is meant by the *three dimensions* of a solid? What is the bulk of a block of wood 2 metres long, 1 decimetre thick, and 7 centimetres deep?

The edge of a cubical block of a solid expands when heated by 1-100th of its length. Compare the superficial area of one side of the cube and the cubical contents of the cube at the higher temperature with the corresponding dimensions of the cube before being heated.

How is the linear expansion of a solid found?

Show that, in the table given on page 14, it is quite unnecessary to mention any particular length, the abstract numbers —·0086, &c.—giving all the information required.

What is the meaning of the term *specific* as applied to expansibility? What is the *relative* linear expansibility of copper as compared with that of glass tube?

Enumerate some of the circumstances that affect the expansibility of a solid.

If a compound bar is straight at the ordinary temperature, what would be the effect of immersing it in an exceedingly cold liquid?

How do changes of temperature affect time-pieces?

Describe the structure and the use of Daniell's Pyrometer.

Describe the methods for ascertaining the cubical expansion of solids by direct experiment; and show how these presuppose a knowledge of the real expansion of some liquid.

Describe experiments that prove the different conductivity of substances for heat.

How is the conductivity of a solid measured?

Describe accurately the difference between the apparent and the real expansion of a liquid.

How is a thermometer made? Why is it absolutely necessary to have two fixed points on the tube? What are these two points?

How many thermometric scales are there in common use, and what relation subsists between them?

What are the peculiar advantages of an alcohol thermometer?

Describe Rutherford's Minimum Thermometer.

Describe experiments to show the convection of heat by liquids.

Explain the use of the common barometer; and show how it is affected by changes of temperature.

How can the absolute expansion of a liquid be deduced from its relative weights at different temperatures? How were the latter determined, in the case of mercury, by Dulong and Petit?

What knowledge do we gain from the statement that the mean coefficient of expansion of ether between 0° and 10° is ·00152?

Describe the deportment of water when heated from 0° to 100°; and show how this affects the rate of cooling in fresh-water lakes.

What is Gay-Lussac's law with respect to gaseous expansion? How far is it in accordance with the results of later experiments—especially those of Regnault on the expansion of gases under great pressure?

How is the expansion of a gas employed for determining temperatures?

What currents of air are produced when a fire is lighted?

What is the course of the lower trade wind in the southern hemisphere?

Which is the readiest means of ascertaining at what temperature the vapour of a liquid begins to be a perfect gas?

How are gases weighed, and what precautions have to be taken during the process?

Describe one of the methods of determining the rela-

tive weight of a vapour. How does this method differ from the other described in the text?

As compared with hydrogen under similar conditions of temperature and pressure, the relative weight of a certain gas is 10 at 85°·76m. B.P., but is 12 at 327° ·76m. B.P. What is the mean coefficient of expansion of the gas between 85° and 327°? Find also the calculated coefficient of expansion of the gas at 0°.

The relative weight of a gas at 15° is 20 (as compared with hydrogen at 0°). When the gas is heated to 20°, it expands more than a perfect gas would do in the proportion of 156 to 155. What is the relative weight of the gas at 100° (as compared with hydrogen at 100°), supposing that the gas expands uniformly between 15° and 100°?

Explain the discovery which Dr. Black made with regard to the conversion of water into steam.

Enumerate some familiar instances of the disappearance of heat during evaporation, and of the evolution of heat during condensation.

Describe experiments which prove that water evaporates at all ordinary temperatures.

How is it proved that the potential heat of steam at 100° is 537?

State precisely what is meant by the tension of a vapour.

What is Dalton's Law of the Tension of Vapours, and how far is it true?

How could you convert a gas into a saturated vapour without altering the pressure upon it?

Draw a figure of Thilorier's Condenser. Describe its *structure* and its use.

What is a freezing mixture?

Give examples of the evolution of heat during solidification.

What is the meaning of the term Relative Heat? Describe the several methods of ascertaining the relative heats of solids and liquids.

State clearly what information we derive from the fact that the relative heat of silver is ·057. To what temperature will a gramme of silver at 0° be raised by the application of 1 gramme-unit of heat to it?

Explain Dulong and Petit's Law of Atomic Heats.

If 10 cubic centimetres of mercury at 100° are shaken up with 5 cubic centimetres of water at 0°, what will be the temperature of the mercury or of the water, supposing that none of the heat is lost? Find also the bulk of the water after agitation.

What conclusions can be drawn from the study of the relative heats of gases under various conditions?

Explain distinctly what is meant by the expression—

Mechanical Equivalent of the Unit of Heat.

How has the mechanical equivalent of unit of heat been determined experimentally?

What quantity of force would be required to compress 1 gramme of steam at 100° ·76m. B.P. into water at 100°, supposing that the heat produced by the compression was continually removed?

Give some familiar cases of the conversion of mechanical force into heat.

How much heat is evolved by the combustion of 3 kilogrammes of carbon in air?

What quantity of carbon must be burnt in the air so as to produce as much heat as is obtained by the combustion in air of 32 grammes of sulphur?

Enumerate some of the sources of heat.

What part does a plant play in the economy of nature?

Distinguish between radiation, conduction, and convection of heat.

How can radiant heat be reflected?

Explain the theory of exchanges.

What connection is there between the absorbents and the radiators of heat?

How is the absorption of heat affected by colour?

Enumerate some of the more important conclusions derived from the study of the absorption of heat by gases.

How would you prove that waves of heat may strike against a substance, or even pass through it, without causing rise of temperature?

Why is glass used for hot-houses and for fire-screens?

Tea remains hot longer in a silver tea-pot than when it is in one of earthenware. Explain this.

INDEX.

B.

C.

N.

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THE END.

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MARK LANE.

[*For Critical Notices see next page.*]

CRITICAL NOTICES

ON

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